Alfalfa leafcutter bee management in Western Canada

Agriculture
Canada

Publication 1495/E

Canada

Agriculture Canada Publication 1495/E
available from
Communications Branch, Agriculture Canada,
Ottawa K1A 0C7

Cat. No. A53-1495/1984E ISBN: 0-662-12857-5
Printed 1972 Revised 1984 Reprinted 1989 6M-8:89

Également disponible en français sous le titre
L'élevage de la découpeuse de la luzerne (mégachile) dans l'ouest du Canada.

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Introduction

The alfalfa leafcutter bee, *Megachile rotundata* (Fabricius), is the only bee in Western Canada that can be relied upon to efficiently and effectively pollinate alfalfa. Several bee species, including bumble bees and native leafcutter bees, are efficient pollinators, but their populations fluctuate widely from year to year. Also, their populations have decreased because nesting habitats were reduced or destroyed by land clearing, refuse burning, soil cultivation, and irrigation. Thus, there are not enough native pollinators to adequately pollinate alfalfa. With the introduced alfalfa leafcutter bee, alfalfa seed can be produced economically wherever the bee can thrive and where growing and harvesting conditions are good for alfalfa.

The loose-cell system of leafcutter bee management was developed to manage the large populations of bees required to pollinate the crop. This system enables easy removal of the bee cells from laminated grooved nesting materials for storage over the winter, without destroying the nesting material. The system enables control of parasites and predators through various management procedures, including hive construction, incubation, and removal and tumbling of cells from the hives. It also makes efficient use of cold storage and incubation facilities to synchronize bee emergence with the beginning of flower bloom. The system permits beekeepers to take samples of cells from their current production to accurately estimate numbers of intact cocoons, females, and parasites. By these estimates, improvements in beekeeping practices can be monitored and guidelines provided when bees are bought, sold, exported, and rented by alfalfa-seed growers. Although the loose-cell system of bee management requires substantial financial investment in specialized equipment and demands intensive and proper handling of bees, careful managers realize profits from the sale of excess bees that are often equal to the sale of the seed.

Alfalfa seed grower associations

Alfalfa seed grower associations in the provinces of Alberta, Saskatchewan, and Manitoba provide information on alfalfa seed production

and on leafcutter bee management through annual meetings, field days, and newsletters. Problems concerning seed and bee production are discussed and recommendations affecting the industry are made to appropriate authorities. The associations provide lists of beekeepers who have bees for sale. A common objective of these organizations is to provide guidelines for the Canadian Leafcutter Bee Cocoon Testing Centre. This is done by monitoring the quality of bees and attempting to establish grading and selling standards.

Natural history

The genus *Megachile* includes all so-called leafcutter bees that make nests with pieces of leaves or petals but does not include species that use resin, mud, or other such materials. There are about 115 species of leafcutter bee in North America, of which about 22 species occur in Western Canada. The alfalfa leafcutter bee is of Eurasian origin. It is smaller than native leafcutter bees and the scopa, the pollen-collecting hairs on the underside of the female's abdomen, is silvery gray. Other female leafcutter bees usually have a golden, tan, or black scopa. Female alfalfa leafcutter bees (Fig. 1) are larger than males, have a pointed oval-shaped abdomen that contains a sting and parallel rows of conspicuous pollen-collecting hairs, and a few gray hairs on the face. The male (Fig. 1) has a straight-sided truncated abdomen, no pollen-collecting hairs, considerable yellow hair on the face, and slightly longer antennae.

All leafcutter bees are solitary by nature, although the alfalfa leafcutter bee is also gregarious. At the hives, the female makes her own nest or nests, collects provisions, lays eggs in the cells, and has little interaction with other females of either her own generation or the daughter generation. The inclination of the alfalfa leafcutter bee to live close to neighbors is one of the main reasons why it can be domesticated. Other reasons for easy domestication are as follows: it will live in man-made dwellings; beekeepers can synchronize bee emergence with beginning of flower bloom; and the bee does not forage far from its hive, as do honey bees or bumble bees. Some of our native leafcutter bees will live in man-made dwellings, but they are not gregarious, and even if they are present in considerable numbers, they will not stay where they are placed.

Emergence of adults from prepupae stored over the winter at 5°C and incubated at 30°C begins on the 20th day of incubation and ends on the 31st day. About 50% of males emerge before the females begin to appear (Fig. 2); emergence of males peaks on the 22nd day and of females on the 24th and 25th days. By the 25th and 27th days, 95% of the males and females, respectively, have emerged. The beginning and length of the emergence period, the sequence of emergence of the sexes, and the rate of prepupae mortality vary with the temperature that prepupae are exposed to before storage, the winter storage temperature, and the length of storage. Cocoons cannot be stored for a second year.

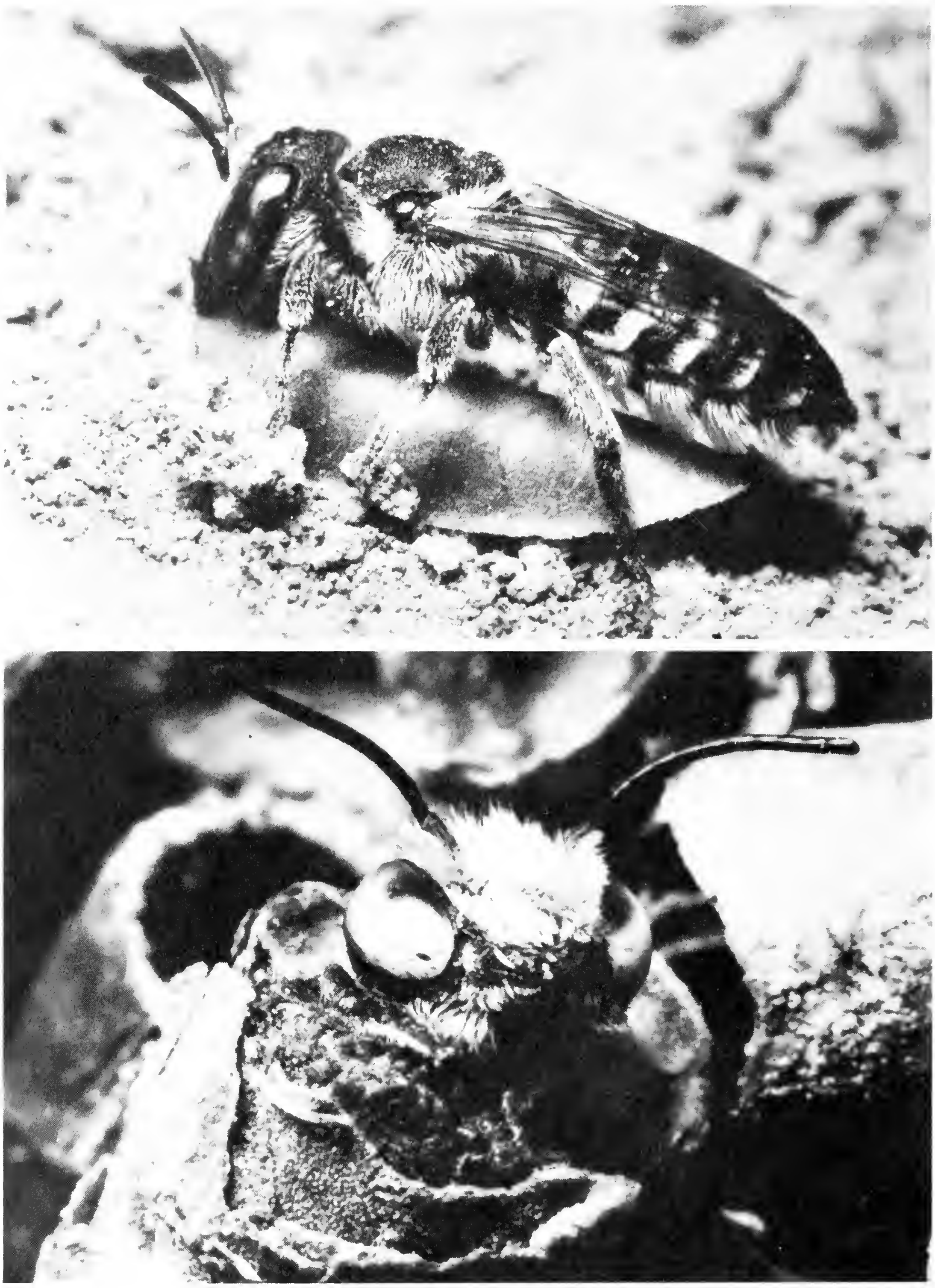


Fig. 1 *Megachile rotundata* (Fabricius), alfalfa leafcutter bee; female (*above*) and male (*below*).

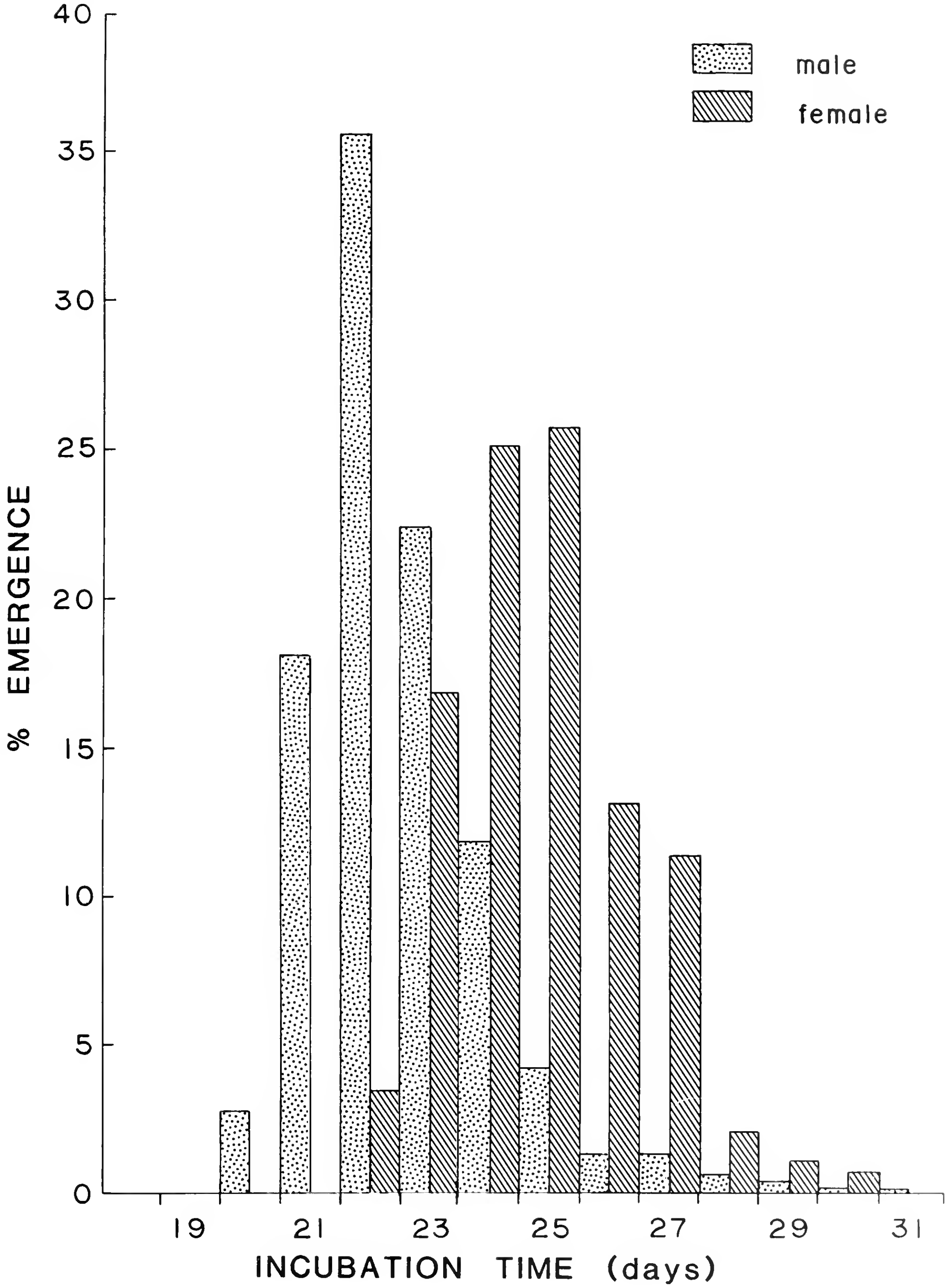


Fig. 2 Emergence pattern of alfalfa leafcutter bees incubated at a constant 30°C until emergence is complete.

Females mate soon after they emerge from their cocoons. Females mate only once, but males can mate several times. Females retain enough sperm in their spermatheca, an organ that stores sperm, to fertilize all the eggs they are capable of laying. Eggs begin to develop soon after mating. While the eggs develop, the females feed on both pollen and nectar, find and orient to a suitable nesting tunnel, and begin construction of the first cell.

To construct and provision a cell, the female leafcutter bee must select, cut, transport, and place suitable leaf material in the tunnel as well as collect pollen and nectar. Females prefer soft and pliable leaves to harsh and turgid ones, and readily use alfalfa leaves and flowers as well as other plants, such as clover, buckwheat, roses, lamb's-quarters, and sage. They sometimes partly or completely cut and discard several leaves before finding a suitable piece. Females cut leaves with their mandibles and hold them next to their body with their legs (Fig. 1). The average weight of a female leafcutter bee is about 35 mg; a bee cuts loads of leaf pieces equal to about 17% of its body weight. The size of a piece of cut leaf probably depends upon the pivot point used by the bee while cutting the piece and would be the same for all types of leaves.

The front end of the leaf piece is pinched between the mandibles as it is carried to the tunnel. Several oval leaf-pieces are taken to the back of the tunnel and placed in overlapping layers, forming a thimble-shaped cell with a concave bottom. The leaf pieces are cemented together by either a salivary secretion or juices from the leaves. The number of leaf pieces used to make each cell varies with the diameter of the tunnel. In tunnels that are 6.4 or 7.2 mm in diameter, about 14 or 16 leaf pieces, respectively (range: 8–27), are used to make a thimble. An additional two or three leaf pieces form the cap, which is cut and attached to the cell after egg laying. Females nesting in large holes usually use up to 37 leaf pieces to reduce the cell size so that it fits the dimensions of the tunnel. Edges of these leaves are often flared and poorly attached to other leaves. Females almost always finish constructing a cell before provisioning it. Under ideal foraging conditions a cell is constructed in about 2½ hours.

In collecting provisions the alfalfa leafcutter bee prefers several pollen and nectar sources, accepting alfalfa readily when it is the closest and most abundant. It also pollinates sweetclover, alsike clover, sainfoin, birdsfoot trefoil, and cicer milkvetch. On alfalfa flowers the females force apart the keel, insert their tongue into the corolla, and suck the nectar. The stamens and pistil, held under tension by the keel, are released and flip up, hitting the female under the head and on the front part of the thorax between the legs. Pollination of the flower then occurs. The female collects pollen by transferring it from forelegs to middle legs to hind legs and to the scopa. Females often crawl from one flower to the next on the same raceme before transferring pollen. Females returning to the nest enter head first, regurgitate the nectar, somersault in the tunnel, back up to the provisions, clean the pollen from the scopa with rapid hind-leg movements, and tamp the pollen–nectar paste into position with the tip of the abdomen.

Females collect about 80% pollen and 20% nectar in their first load of provisions, increasing the amounts of nectar in subsequent loads. The final load or two is entirely nectar. Since a female gathers different amounts of nectar on each trip, she probably returns to the nest when a certain load weight is reached, rather than when her honey stomach is full of nectar. Maximum provision loads are about 23% of female body weight. The total provisions for each cell consist of about two-thirds nectar and one-third pollen, and are collected over 15–27 provisioning trips. The amount of provision and size of progeny are related to the tunnel diameter, not to the size of the mother bee. Cells that produce females are provided with more food than those that produce males, and thus females grow larger. Under ideal foraging conditions, it takes a female as long as 5 hours to provision a cell.

The number of flowers visited per trip, the time spent flying from flower to flower and at each flower, and the number of flowers tripped per unit time are influenced by weather conditions (i.e., temperature and light intensity), agronomic practices (i.e., plant or flower density and irrigation), and alfalfa cultivar. Females have been observed to visit from five flowers per minute under cool, partly cloudy weather conditions in a thin plant density, to 25 flowers per minute under hot, clear conditions in a thick plant density. Each flower visit averaged approximately four times longer under the first condition, but the percentage of flowers pollinated under both conditions was similar.

The first eggs are laid within 7 days of placing the bees in the field. It usually takes less than 1 minute for the egg to be inserted into the nectar–pollen paste. After the first cell is finished in a tunnel, the female immediately begins construction of the next cell and continues until the tunnel is nearly filled. Depending upon tunnel length, from 8 to 12 cells are constructed in a tunnel (Fig. 3).

The female almost always lays female eggs in the inner cells and male eggs in the outer cells of each tunnel. When the tunnel is filled with cells, 10–50 circular leaf pieces are cemented together and form a solid plug, which usually lies flush with the tunnel entrance. This plug is probably provided by the female to protect her offspring from parasites, predators, and inclement weather.

The time required for egg and larval development depends on temperature. At 15°C it takes 15 days for eggs to hatch and 35 days for larvae to reach the prepupal stage, whereas at 30°C it takes 2–3 days for eggs to hatch and 11 days for larvae to reach the prepupal stage (Fig. 4). The diet of the larvae is initially high in nectar or soluble carbohydrates. As the larvae develop through four instars, the pollen content of their diet increases. Larval weight increases rapidly between 5 and 8 days after egg hatch at 28°C and maximizes in 11 days. Larval mortality occurs mainly in the first or second instar and is often associated with extended duration of temperatures over 26°C or long, cold periods that prevent feeding.

The larvae move about inside the cell. Early in development, the head is in the food but after spinning silk the head is at the cap end. The larvae consume almost all the provisions, deposit a ring of dry fecal pellets

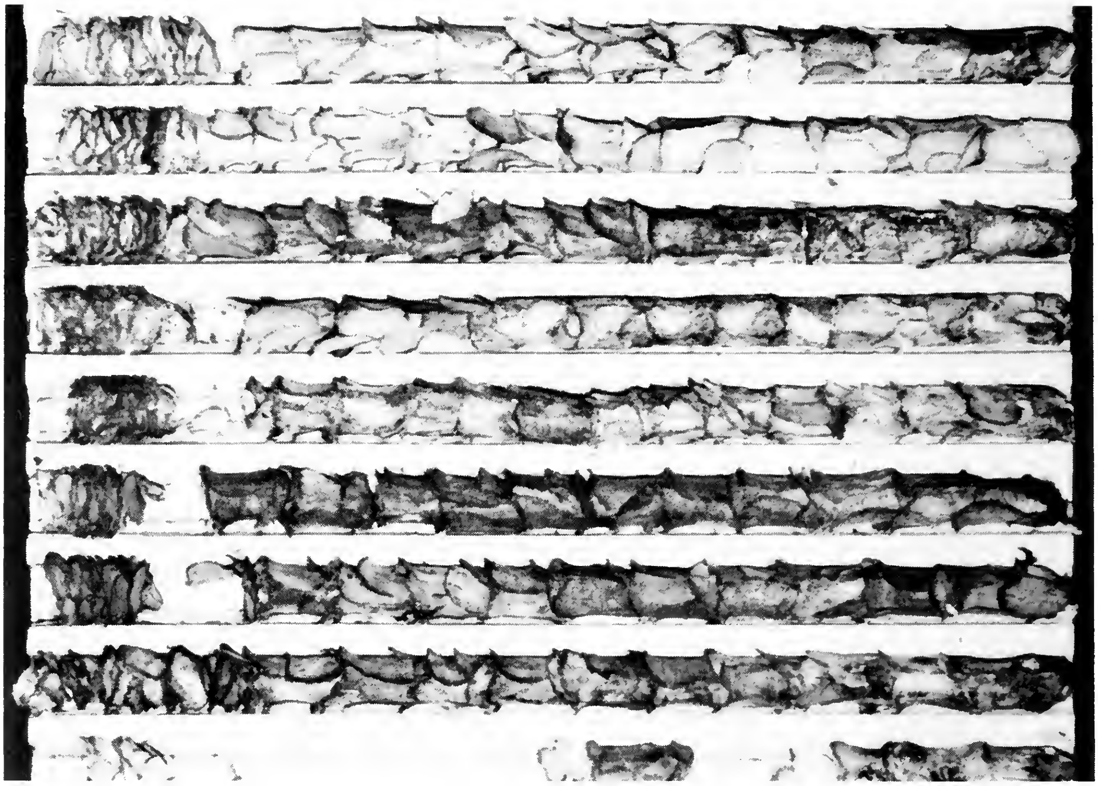


Fig. 3 Cells made of leaf pieces in tunnels made with grooved boards.

Fig. 4 Cells cut open to show egg (*left*), young larva feeding (*middle*), and prepupa (*right*).

beneath the leaf pieces in the cap, and spin a tough silken cocoon to separate themselves from the contamination. The bee overwinters as a prepupa in this cocoon.

In spring and early summer or after the prepupae are removed from storage over the winter and placed in an incubator, they are completely white (Fig. 4); later the eyes turn pink, then black (Fig. 5) and finally the whole pupa turns grayish black. About 7 days later, the adult bee emerges by chewing out of the cocoon. The sex ratio is influenced by both length and diameter of the nesting hole, but favors males about 2:1.

Temperature and light intensity influence the beginning of flight of males and females. They start foraging under conditions of low temperature and high light intensity or vice versa. When the leafcutter bee was first imported into Western Canada in 1962, it started pollinating alfalfa only when the temperature reached 21°C, which was considered a limitation on the bee's usefulness. In recent years, the bee has evolved so that several individuals now start pollinating at 18°C. Thus, by adapting to new conditions, the bee has become more widely used to pollinate alfalfa. However, high, uniform seed yields and bee production are more consistently attained in those areas with the greatest total heat units. Peak flight occurs during midday and at high temperatures. Decreasing light intensity appears to be the main factor that ends daily foraging, even though summer temperatures during early evening are often above 20°C. Females usually return to nesting tunnels at night in the southern parts of Canada, but in the Peace River area they sometimes remain in the field. Males often remain in the field overnight in groups or return to aggregate in cracks in the shelter.

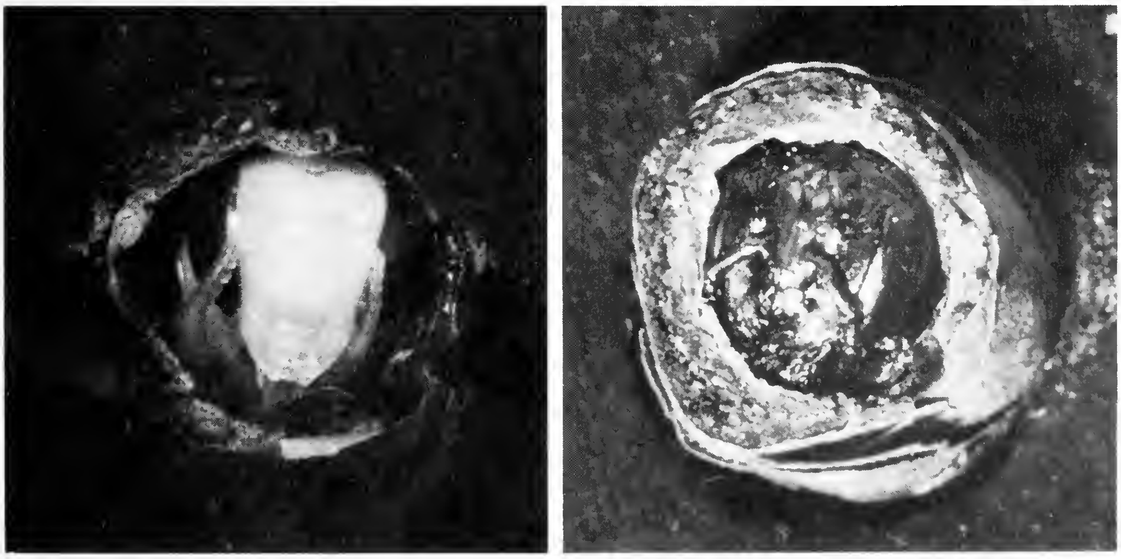


Fig. 5 Cocoons with the head end removed to show white pupa (*left*) and dark pupa (*right*).

The useful season for the alfalfa leafcutter bee begins when alfalfa starts to bloom and ends when the tripped flowers do not have time to set mature seed before frost. In southern Alberta, the pollinating period usually starts between 15 June and 1 July and ends between 10 August and 20 August. The length of the pollination period depends upon cumulative heat units available during the spring and summer. In areas with few heat units, this period may start late and end early. The survival curves for males and females differ (Fig. 6). The males die steadily: 50% of the males are dead 15 days after they are placed in the field and few live longer than 35 days. A fairly constant percentage of females die per unit time under normal environmental conditions: 50% of females are dead after 40–50 days and few live longer than 60 days. The survival curve for males varies little from year to year, but for females it varies according to weather conditions. In cool, wet summers the females forage for shorter periods each day and survive longer than they do in hot, dry summers. The time to remove the bees from the field is partly governed by weather conditions, which also influence female bee density, the chance of setting mature seed before frost, and the chance of females successfully producing additional offspring.

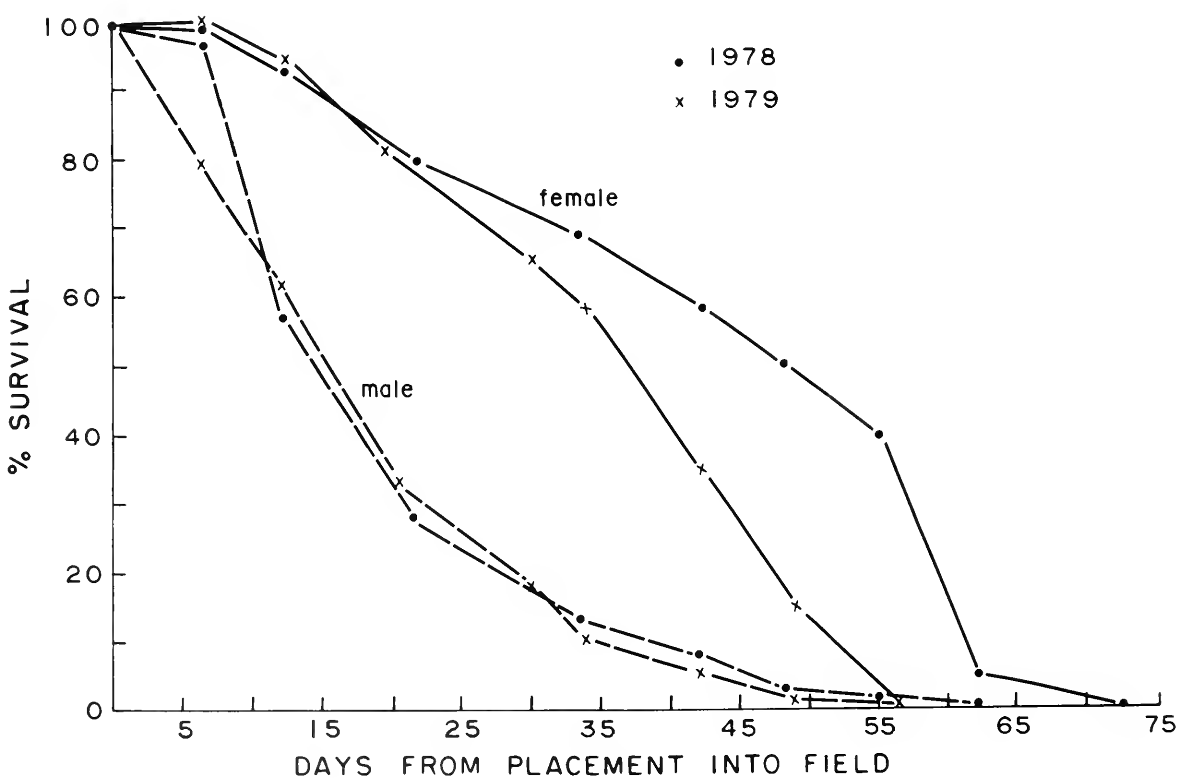


Fig. 6 Survival curves of male and female bees after they are placed in a field.

Management

Obtaining bees and handling them on arrival

Enough Canadian bees are now available for Canadian demands. As beekeepers became more numerous and efficient, and supplies of bees increased, Canada began to export bees, mainly to the United States. Now Canadian beekeepers lead the world in exports of good-quality leafcutter bees. Foreign demand for our bees is high because of low larval mortality rates, low infestations of parasites and predators, and a low incidence of disease. A list of producers of leafcutter bees can be obtained from the alfalfa seed grower associations in Alberta, Saskatchewan, and Manitoba. Bees can be imported from the United States or from other foreign countries only on a restricted basis. To prevent the introduction of injurious insects and plant diseases from foreign countries, a permit is required from Agriculture Canada, Plant Quarantine Division. It is best to obtain bees only from Canadian sources to prevent introduction or movement of bee parasites, predators, or diseases. Bees obtained in one area of Western Canada readily adapt to other areas.

When buying bees, examine the quality by following the procedures outlined in this publication in the section on estimating production. Also, ask your supplier for a copy of the test results from the Canadian Leafcutter Bee Cocoon Testing Centre concerning the batch of bees you are planning to buy. The price of bees varies and is dependent upon quantities available and export demand. You can expect to pay more for high numbers of live bees per unit weight, a high percentage of females, and low percentages of parasites, predators, and disease.

When the bees are received, put them in a cool, dry, mouse-free area maintained at about 5°C. If bees are stored in a cool, damp place such as a root cellar, store the cells in sealed containers to prevent them from absorbing moisture and becoming moldy. Open the containers once or twice during the winter to allow fresh air to enter and to impede the growth of mold.

Equipment

The methods and equipment described in this publication were designed to enable you to manage millions of alfalfa leafcutter bees efficiently. The shelters were designed to ensure a minimum number of alterations to standard 1200-mm × 2400-mm sheets of plywood. All equipment can be transported on pickup trucks, utility trailers, or low flatbed trailers towed by a light truck or car. All parts are made with precision and are therefore interchangeable. All pieces of the same type are of uniform size and thus can be stacked easily, and all were designed with the bee and its parasites or predators in mind. All measurements are metric; therefore, be sure conversions are correct. New construction equipment (e.g., saw blades) of metric measurement may have to be

purchased to ensure that wood measurements and saw cuts are compatible. The equipment recommended here was designed for specific reasons; be sure these reasons are understood before modifying, making, or buying equipment designed by someone else.

Hives

The leafcutter beehive is where the females construct and provision cells and lay eggs. It is also where the larvae develop and where parasitism primarily occurs. The hive requires precise construction of good-quality materials to ensure a high return of viable cells by providing an acceptable, parasite-free home for the bees.

Commercially available nesting materials are laminated grooved pinewood or polystyrene. Hives are constructed with fir plywood frames. The back of a wooden hive is made of hardboard, and the back of a polystyrene hive is made of aspen flakeboard with four rows of 25-mm diameter holes. These holes allow air to circulate within the tunnels and reduce the growth of mold on and in the cells. A pinewood hive has about 2500 tunnel holes and weighs about 20 kg, whereas a polystyrene hive has about 3000 holes and weighs about 6 kg.

The wooden boards each have 13 tunnels and the polystyrene boards have 30. In commercially available nesting boards, tunnel diameters for the wood are presumed to be constant throughout a hive but may vary from 5.5 to 6.8 mm in diameter depending upon milling precision, supplier, and shipment; for polystyrene, the tunnels are uniform and are alternately 6.4 and 7.2 mm in diameter. Since bees tend to nest in the smaller tunnels first, nesting bees are often separated by empty tunnels in polystyrene hives. Thus, the bees are induced to nest throughout the polystyrene hives, and congregations conducive to the growth of mold are avoided. Tunnel diameters of 6.4 and 7.2 mm are optimum for the production of female bees and viable cocoons, for increasing the size of bees, and for requiring few leaf pieces to construct a cell.

Both nesting materials (available from several suppliers located in Western Canada) can be reused over several years, but wood appears to last longer than polystyrene. The wooden material can be bought precut to the desired tunnel length or in lengths of 300, 600, 900, or 1200 mm. Polystyrene is manufactured only in tunnel lengths of 95 or 115 mm. Tunnel lengths of between 100 and 150 mm are optimum for production of cells per capped tunnel, because most of this tunnel length is used by the females when constructing and provisioning cells. Tunnel length has little effect on the percentages of viable cocoons or female bees produced.

Bees produce more cells and a higher percentage of viable cocoons in wooden than in polystyrene hives. However, more females are produced per hive in the polystyrene because the tunnels are of a larger diameter. Bees may prefer wood to polystyrene because it more closely resembles their natural nesting site. The percentage of viable cocoons is greater in wood because plant foliar molds (i.e., *Penicillium* spp., *Aspergillus* spp., and *Rhizopus* spp.), which are carried on the leaf pieces, do not develop on and

in the cells to the same extent. Apparently, wood absorbs moisture but polystyrene does not. Recently, some beekeepers changed from polystyrene to wood because they developed allergies when exposed to the mold spores.

The polystyrene material is warmer than wood by 3.5°C or more, depending upon time of day and ambient air temperature. In northern latitudes, the warmer material may be more advantageous because it provides heat, thereby assisting larval development and commencement of adult flight. But sustained heat above the ambient air temperature over several days can increase mortality of early instar larvae. No differences have been found in rates of parasitism between the two materials.

Hives are designed for easy handling and stacking. Plans for hives made from pine boards and polystyrene boards are given in Figs. 7 and 8.

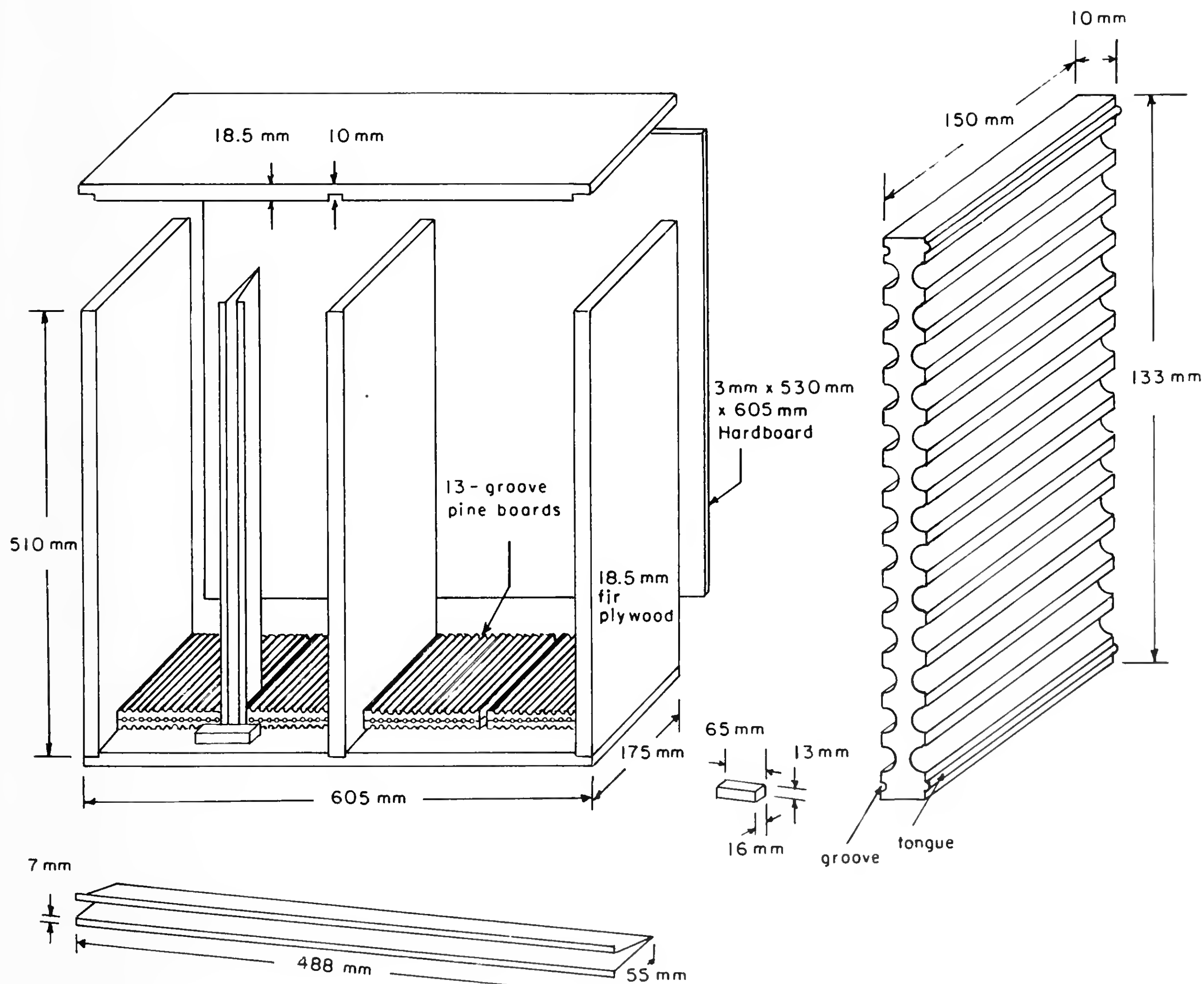


Fig. 7 Plan for a hive made with 13-tunnel pine boards and a metal divider.

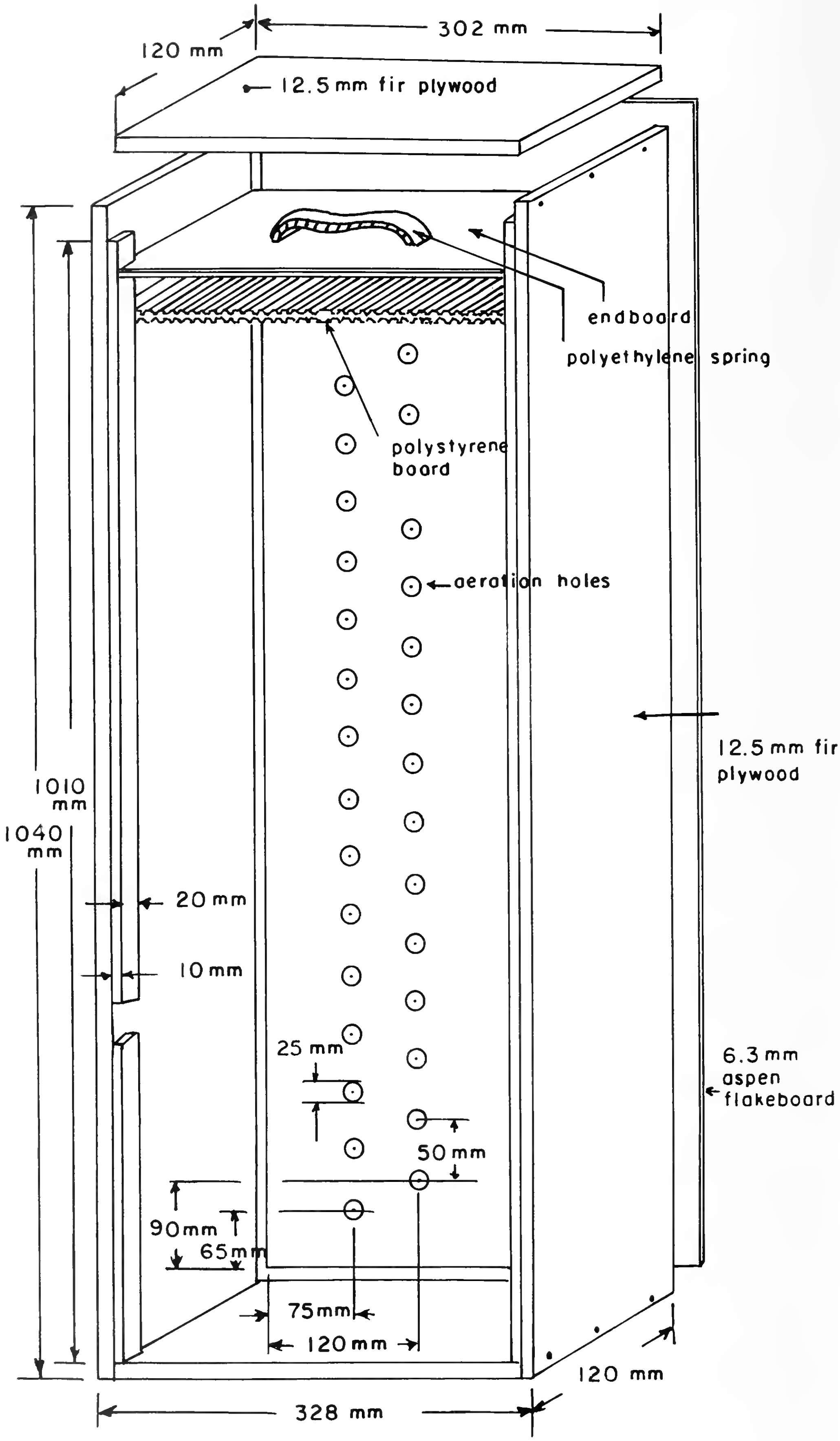


Fig. 8 Plan for a hive made with 30-tunnel molded polystyrene grooved boards.

Hives made with wooden grooved boards are easier to handle if they are made almost square rather than oblong. Make hives as precise as possible so that all parts are interchangeable. Make sure that all cuts on both hive parts and grooved boards are made accurately at right angles. The better the parts fit, the fewer will be the invasion routes for parasites. All joints are nailed and glued to ensure rigidity, even when the hive is jarred or dropped. When a poorly nailed hive is dropped, the back often bulges, providing room behind the tunnels for parasites to move around.

Make sure that all wooden grooved boards fit snugly against the insides of the backs of the hives by squaring the ends of the boards before cutting them into the desired lengths. The 600- and 1200-mm lengths of grooved board often are not exactly square. If the end is not cut precisely square, the board will not fit against the back of the hive and the ends of as many as 26 tunnels will be exposed to invasion by parasites. Cut the grooved boards to the required length in pairs and reverse one of the pairs, end to end and side to side, before beginning to square or cut. Manufactured boards may be slightly thinner on one side than on the other. Reversing one of the boards compensates for this imperfection. Use a fine-toothed saw blade to reduce splinters. Brush or burn slivers off both sides of the board. Any slivers left on the ends of the tunnels may prevent the boards from fitting firmly against the backs of the hives, thus leaving avenues of entry for parasites.

In hives made with polystyrene boards, the 25-mm diameter holes in the aspen flakeboard back are covered from the inside with wire screening to prevent mice from entering. The screen is stapled to the back. Polyurethane foam, 5 mm thick, is then laid across the screen to reduce the amount of light entering. Foam allows more air to circulate than does paper and provides a tight fit against the grooved boards.

Parasites lay their eggs in the cocoons of the bees. The easiest way for parasites to reach the cocoons is to crawl along cracks in nesting materials, warped boards, or behind the backs of the tunnels. Spaces at the back and sides of the hive should be eliminated and imperfect boards should not be used. Warped boards will break when they are put through the automatic cell remover. When this happens, cells are crushed and the machinery may have to be stopped to remove jammed parts of broken boards. The strips of wood that hold the boards and end boards firmly against the back also block the entrances along the sides of the hive. Excess space can be eliminated by placing a sheet of 5-mm thick polyurethane foam across the back of the hive. Because the foam fits firmly against the grooved boards and expands slightly into the tunnels, it reduces the possible entry of parasites. The polyurethane sheet foam may have to be replaced yearly if too many holes are chewed into it by second-generation bees or by larvae of the driedfruit moth.

Details are given for an endboard (Fig. 9) that prevents bees from nesting in the half-tunnels at either end of a hive and that provides a pressure plate for the spring that holds the boards firmly together. The plate also prevents mice from nesting in the polystyrene material. A

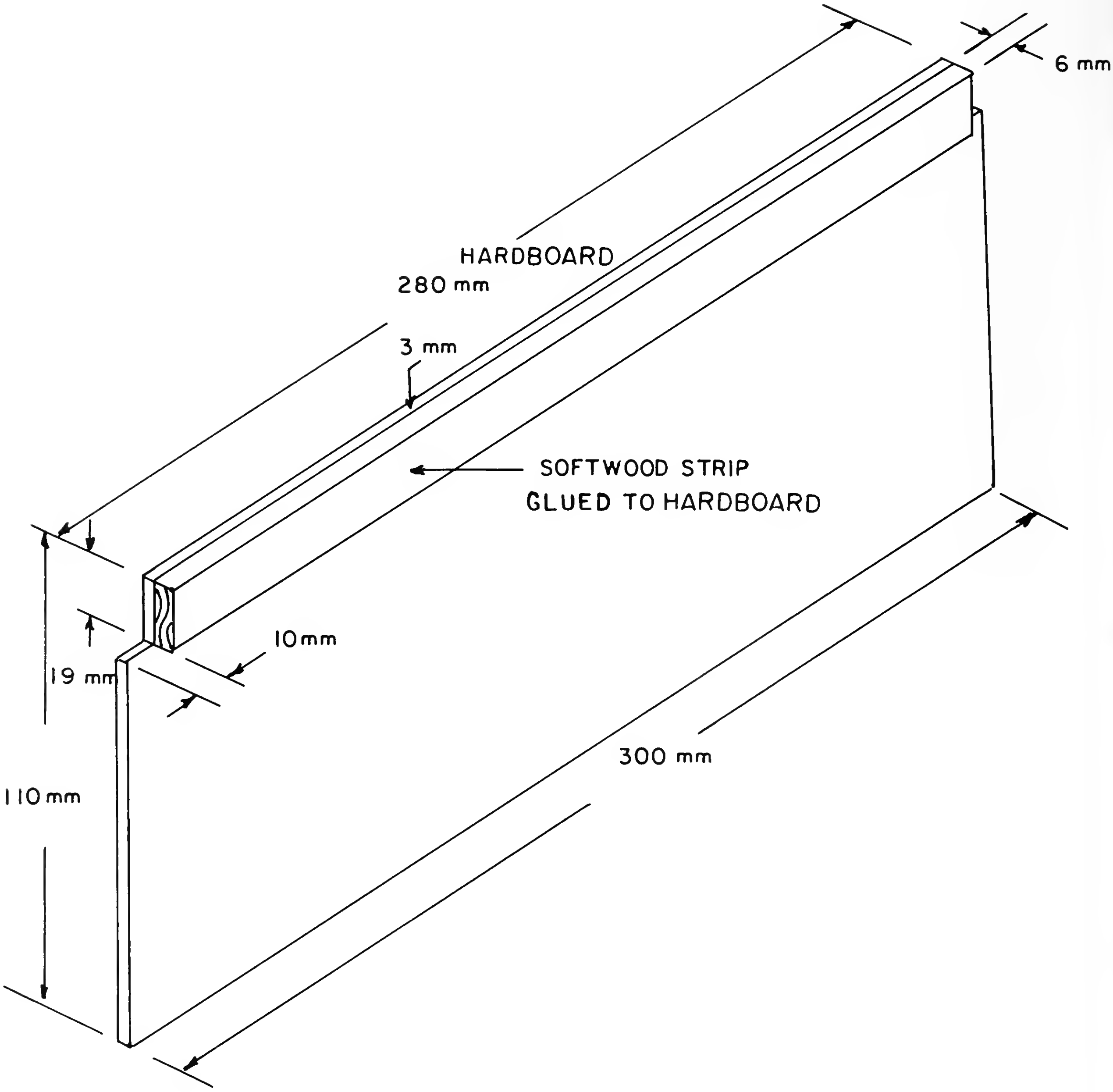


Fig. 9 Plan for the endboard of a hive made with polystyrene grooved boards.

0.9-mm (20-gauge) galvanized metal divider (Fig. 7) under tension provides pressure against the outside walls of the wooden hive, thus holding the wooden boards in position and reducing avenues of entrance for parasites. Springs for holding either wooden or polystyrene boards can be made by cutting rings 25 mm wide from black polyethylene pipe 38 mm in diameter and then slitting and stretching them to form springs. The springs allow for the expansion or contraction that takes place as the bees fill the tunnels with moist leaves, honey, and pollen or when the cells and boards dry.

To assemble a hive with polystyrene boards (Fig. 8), position the endboards and align all the grooved boards to form tunnels. Make sure the boards are vertical, not slightly diagonal, by shaking and pressing them into position; then insert the spring. Fix the grooved boards and endboards (Fig. 9) firmly against the back of the hive by pressing two spruce or pine strips into position along the front inside edges of the sides of the hive and then nailing them to the sides. The side strips should fit flush against the bottom end of the hive so that the endboard at the top can be removed through the space between the ends of the strips and the top of the hive; the strips cannot be removed until the top endboard is removed. To assemble a hive with wooden boards that have tongues and grooves at both ends (Fig. 7), stack four columns of boards in the hive and insert the metal dividers between the columns; then insert a spring at the end of each column. A tight fit requires inserting the tip of the divider first and slightly contracting the V as it slips into the gap between the two columns of boards. To ensure that the dividers hold the boards firmly against the backs and sides of the hives, nail small wooden blocks into the hive at the end of the divider. Bolts with large washers can also be fastened across the top of the metal divider and through the back of the hive.

Before painting the faces of the hives, assemble the boards in the hives and insert the springs so that the boards are held firmly together. Spray the paint lightly so that it will not seep down between the boards and cause them to stick together. Apply paint sparingly to polystyrene boards; paints that contain petroleum solvents (such as Varsol®) can dissolve the polystyrene. Use flat exterior oil base paints. Bees prefer dark colors to light ones, no matter what the material, and prefer hives with color patterns to those left unpainted or painted in solid colors, even when the solid color is black. Light blue on a black or charcoal background is highly attractive to the alfalfa leafcutter bee. The pattern, whether it is a Hertz pattern or your name, should cover no more than one-third of the face of the hive. The bees prefer highly dissected patterns because they are a tunnel-finding aid for approaching females. Make the hives as attractive as possible or the bees may leave them and nest between the shingles of nearby buildings.

To make a sturdy stencil of the Hertz pattern or of your name, trace the pattern with a pencil on a sheet of 0.6-mm (24-gauge) aluminum and score the tracing with a utility knife. Score deeply, especially at the corners, and punch the corners so that you can grasp them with pliers and tear out the scored pieces. At the top of the stencil, attach a tab with masking tape so that the stencil can be moved easily from hive to hive. To prevent smearing, clean the stencil with a solvent when necessary.

Decontamination of hives and bee cells

To decontaminate a hive and polystyrene grooved nesting material of plant foliar molds, remove the boards from the hive and put them in a decontamination frame (Fig. 10). Each frame, made of 6-mm metal rods, holds about 100 boards. Two persons need four decontamination frames

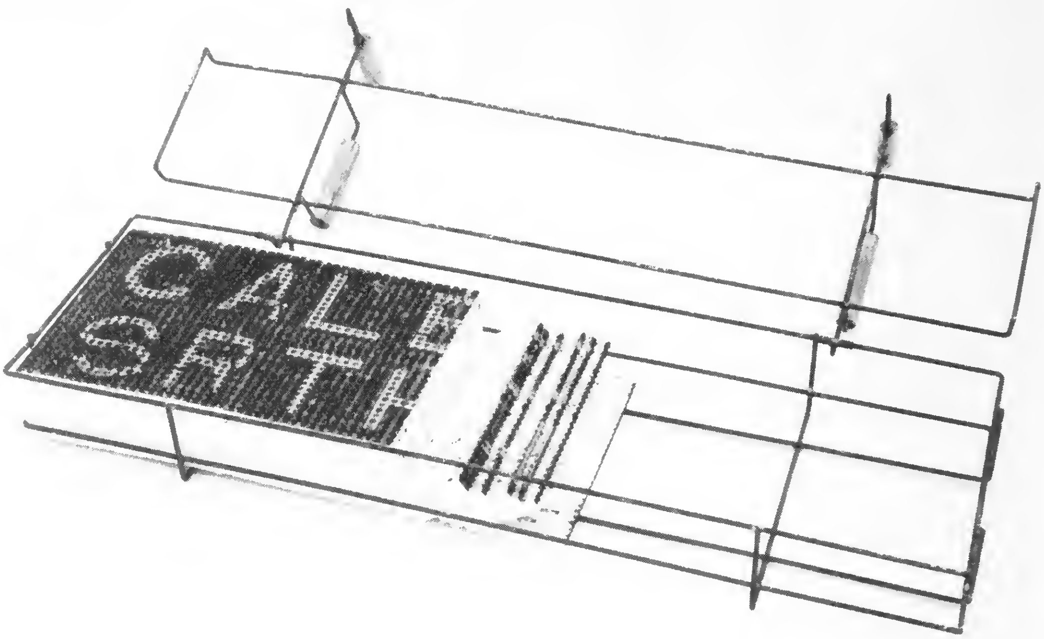


Fig. 10 Decontamination frame for polystyrene grooved boards.

to operate efficiently. Submerge the boards in a solution of household bleach (6% sodium hypochlorite) and water (1:3 by volume) for 5 minutes. The boards fit loosely in the frame, allowing the solution to penetrate readily between them. Agitation will remove some of the excess material sticking to the tunnel walls. Allow the boards to dry thoroughly before replacing them in the hives.

Wooden hives and nesting materials sometimes become covered with mold and require decontamination. Change the ratio of bleach to water to 3:1 and decrease the time to 1 minute. Because wood swells when it is wet, shake the boards vigorously to reduce excess moisture and allow them to dry thoroughly before replacing them in hives.

Steam cleaning can also be used to decontaminate both types of nesting materials. As steam cleaning tends to remove some of the paint from the front of the hives, repainting may be necessary.

Cells do not usually need to be decontaminated. Plant foliar mold spores exist everywhere and contamination occurs readily, so that the practice of decontaminating cells is of questionable value. However, excessively moldy cells can be decontaminated without harming the larvae by submerging the cells for 1 minute in bleach and water (1:3 by volume). Spread the cells over a surface in the open air, but not in direct sunshine, after removing them from the solution. Wait until the cells are thoroughly dry and the odor of chlorine is gone before placing them in the incubation trays and putting the trays in the incubator.

Controlled-temperature room

The proper temperature for incubation and storage over the winter of leafcutter bees depends upon a well-constructed and equipped controlled-temperature room (Fig. 11). The room is one of the most important pieces of equipment used by the beekeeper.

Acting as an incubator, the room ensures a rapid, uniform emergence of adults, allowing bees to be put into the field just as the alfalfa crop starts blooming. Bee development can be regulated to permit the release of bees in favorable weather (i.e., calm and sunny), thus increasing chances of success in reproduction and crop pollination. Development of parasites and predators can be controlled by manipulating the environment in the controlled-temperature room. Proper control procedures can then be implemented at the appropriate time during the incubation cycle. The room can be used to store the bees over the winter once they have been removed from the hives.

Following are some construction and equipment specifications for a controlled-temperature room that will hold about 4 million bees for incubation and about 8 million bees for storage over the winter.

Construction

- Outside dimensions of a room in a corner of a larger room (basement, quonset, or garage): 3650 mm wide, 2230 mm deep, and 3050 mm high with a door 1140 mm wide in the middle of the long wall.
- Floor, walls, and ceiling: 38 × 89 mm spruce studs on edge, with polystyrene insulation (75 mm thick) in between; studs spaced 600 mm apart to permit efficient use of 1200 × 2400 mm polystyrene sheets. Plastic vapor barrier should be placed over insulation and under the inside wall lining.
- Inside lining: 9.5 mm fir plywood sheets, good one side.
- Outer shell (inside larger room): 9.5 mm fir plywood sheets, good one side.
- Door: bevelled and 2340 mm high × 1143 mm wide to allow shelf units to be moved in or out of the room.

Equipment

Adequate attention must be given to refrigeration equipment, heaters, humidifiers, and controls to maintain proper temperatures and humidity.

Cooling 560-watt compressor attached to a 746-watt capacity coil. Two fans that run continuously are mounted on the ceiling (Fig. 11). Cooling fans are required to circulate air and dissipate heat produced while the bees are developing in the incubation trays. Heat released from the bees ranges from 1.1 to 2.3 joules per hour per bee and is especially high just before emergence of adults, when it forms a significant part of the cooling load. The higher value should be used when designing the refrigeration equipment for an incubation chamber.

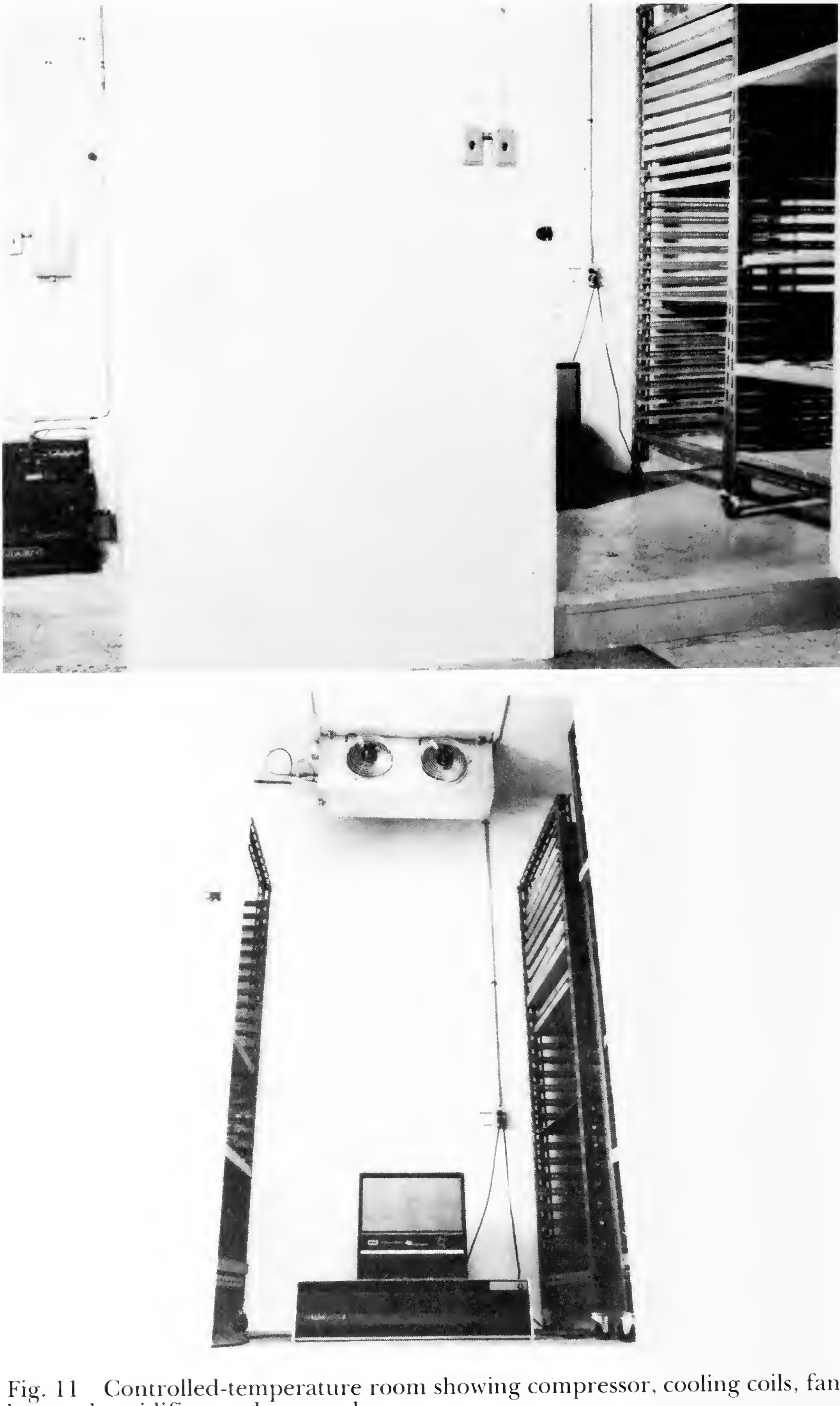


Fig. 11 Controlled-temperature room showing compressor, cooling coils, fans, heater, humidifier, and tray racks.

Heating Blower forced-air baseboard heater located on the floor at the back of the room.
Humidifier Automatic household humidifer set at 70% relative humidity for incubation and 50% relative humidity for storage over the winter, located on the floor at the back of the room. Instead of using room humidifiers, humidity can be increased by wetting the floor or by placing pans of water, wet burlap, or water-soaked cloths in front of fans.
Temperature controls Two thermostats with a control sensitivity of ± 5°C are required, one for refrigerating and one for heating. For winter storage, set the cooling thermostat at 6°C and the heating thermostat at 4°C or 3°C if cells are infested with debris-feeding beetles or moths. These pest insects are inactive at low temperatures. For incubation, set the cooling thermostat at 31°C and the heating thermostat at 29°C.
Electrical switches Two switches outside, near the door, one for the ceiling light and one for the parasite light traps. The fans and lights must be on a circuit separate from the heating equipment so that they can be left on when the thermostatically controlled heating unit is off. The electrical outlet for light traps should be near the floor at the center of the back wall.
Shelf units for the incubation trays Four shelf units with casters to allow movement through the door; for each unit, 27 shelves made of slotted angle iron bolted together. Leave at least 300 mm at top and bottom of shelf unit and 25 mm between incubation trays for air circulation to remove the heat released by the bees. Trays should not be stacked on top of one another, even if crossed. When heat accumulates rapidly in the stack, bee emergence by tray is uneven and parasite control is reduced.

The controlled-temperature room is essentially an enclosed system that allows for little external exchange of heat or moisture. Outside ventilation is not required. Once the correct temperature and humidity within the room have been reached, they are easily maintained with little daily fluctuation. Do not place the controlled-temperature room in direct sunlight, as excess heating may cause the cooling compressor to overwork. A room where the temperature fluctuates little is best. The walls of the incubator should be painted with white glossy enamel and the floor with gray flat enamel for easy cleaning by washing to reduce the growth and accumulation of molds or diseases. To check for uniform temperature, two maximum–minimum thermometers should be placed inside the room (one high and one low on the wall) in addition to the thermostats. The equipment (compressor and cooling coil) needs occasional maintenance, such as oiling and checking the coolant levels. Spare thermostats should be on hand. An alarm system should be installed to warn when temperatures surpass critical highs or lows.

Important factors for incubation and storage

The emergence of adults incubated at 30°C begins with males about the 20th day of incubation and ends with females about the 31st day (Fig. 2). If the cells are placed outdoors on or about the 22nd day,

complete incubation may take a week or so longer because outdoor night temperatures are normally lower and slow down emergence. To avoid dependence on warm weather to complete incubation and emergence in the field, incubate until about 75% of the males and 20–50% of the females have emerged or until the 23rd or 24th day of incubation. Complete emergence in the field should then occur within a few days. The daily release of only adults in the field by returning incubation trays indoors for further incubation is costly in time and labor, especially with large quantities of bees. Also, it may interfere with mating behavior, because males disperse quickly from the shelter and may not find the females that are released later.

Humidity and temperature are critical to the health of the bees during incubation and postincubation storage. If humidity is too low during incubation, the bees' wings are often deformed. When the temperature is lowered, the incubation process is prolonged. At higher temperatures (32°C or more), development can be hindered and bees die. Temperatures in incubators should be lowered in the following circumstances: when inclement weather (cold, wind, rain) reduces the chances of a successful release of bees in the field; when an insecticide needs to be applied to control a pest insect; when time is needed for an insecticide residue to dissipate; and when, through improper incubation timing, the bloom and food on a field are insufficient for the bees. Inadequate bloom early in the season may in part result from drought conditions, late irrigation, or high pest-insect populations.

If no adult bees have emerged, the temperature in the incubator can be reduced to 20°C. Pupae will remain alive at this temperature for at least 10 days. Pupae continue to develop slowly at 20°C, but not at 15°C. Once conditions favorable for release occur, the temperature in the incubator can again be increased to 30°C. A decrease in temperature followed by an increase often results in a rapid emergence of bees.

If release conditions are unfavorable for adult bees that have emerged in the incubator, they can be fed in incubation trays with a honey–water solution (1:1 ratio) sprayed directly onto paper towels laid across the screen of the incubation tray. The paper towels prevent the solution from covering the bees and sticking cells to trays. Do not rub hands or paper towels across the screen when the bees are feeding because bees' tongues extended through the screen are easily broken. If many bees have emerged, feed twice a day and lower the temperature in the incubator to 20°C between feedings, making sure to raise it during feeding. Feeding and fluctuating temperature cause the bees to be less active, use less energy, and survive until release in the field. This tactic can continue for at least 6 days with little loss of bees.

Keep the room dark at all times (no windows or direct sunlight) so that parasites are attracted only to the ultraviolet lights. The ultraviolet lights and water bath for control of parasites and predators are usually placed on the floor between the shelves. Because the small chalcid parasites are poor fliers, it is easier for them to hop down than to fly up to the ultraviolet lights.

After the cells have been thoroughly tumbled to remove excess leaf pieces, debris, and debris-feeding insects, the cells are ready for storage over the winter. They are frequently stored in plastic pails or larger metal or plastic garbage containers. They can also be stored in large plastic garbage bags. Excess humidity in these containers is seldom a problem. Freezing of prepupae rarely occurs if the controlled-temperature room is in the corner of a garage. The prepupae can withstand freezing temperatures as low as −10°C for a short period, with little mortality; however, exposing them to any freezing temperature is not recommended. Cells cannot be stored for more than one season. Check the cells occasionally in storage over the winter to ensure that storage conditions are satisfactory.

Other controlled-temperature rooms

Some beekeepers use separate buildings to incubate or store their bees. These buildings are well insulated, use natural gas for heating, circulate air through a forced-air furnace located outside the building, and humidify using a household humidifier. Chick incubators are excellent for leafcutter bees. The water that provides the humidity and removes the heat created by the chick embryos also provides the humidity needed when the bees are changing from larvae to pupae to adults and removes the heat created by the adult bees.

Incubation trays

Plans for an incubation tray that fits into shelf units in the incubator and shelter and is designed to hold about 30 000 cocoons are given in Fig. 12. The top of the tray is wire screening, which allows heat produced by the adult bees to escape from the tray; in addition, the bees can be fed honey syrup if inclement weather delays removal to the field. The fitted lid is nailed shut after parasite emergence and control and before the first few bees emerge. Plastic incubation trays that hold about 10 000 cocoons can be purchased. The lids on these trays are snapped on before bees begin to emerge and are completely removed from the trays in the field. The trays can be stacked for storage over the winter and scraped or washed to remove moldy cells. When climbing out of the trays, the adult bees grasp the sides of black trays more easily than those of white ones and used trays more easily than new ones. Thus, the sides of new white trays should be scarified.

During long-distance transport to the field, trays should be covered with a tarpaulin to keep bees inactive. Increased activity at this stage can cause premature fraying of wings and some mortality of adults. Spraying with water calms the bees during transportation and retards the rate of release of bees from the trays. If a high percentage of emergence has occurred before field release, a light spraying of water with an atomizer before the lid is opened calms the adults. The rate of release should be slow but continuous, to allow the bees to become oriented to their new surroundings and to reduce the number of bees that drift from one shelter to another. Releasing bees in high winds usually results in drifting.

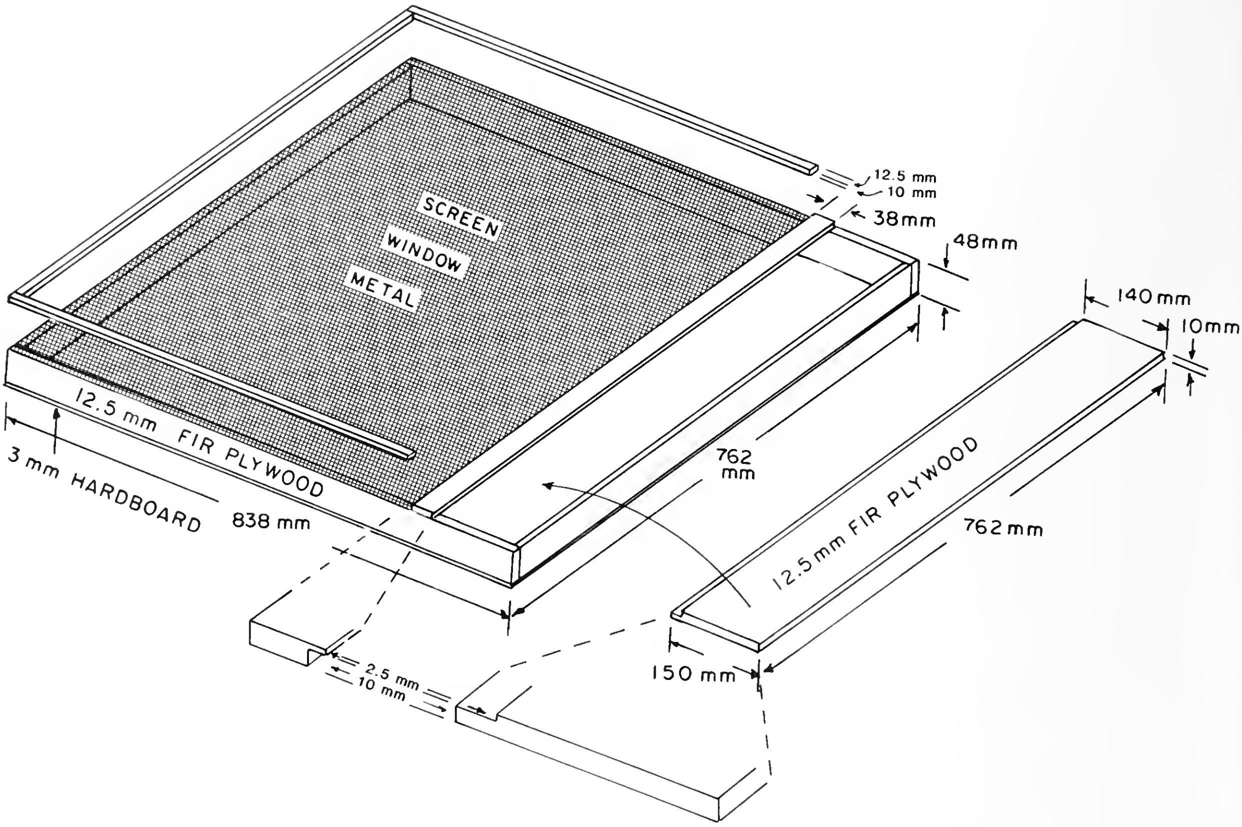


Fig. 12 Plan for an incubation tray.

After the tray has been placed under the roof of the shelter, the lid can be opened wide enough for bees to escape but not for mice to enter. Trays should be placed within 50 mm of the front of the shelter so that sunlight readily attracts the bees to the opening of the tray.

Trays may be removed from shelters 7–10 days after they are placed in the field. By then most of the bees have emerged. To check for complete emergence in the field, inspect the contents of a few intact cocoons by cutting off their head ends with a sharp blade. Continue to check every 3 days until you do not find any live pupae or adults. Bee losses that sometimes occur after the cells are placed in the field include dead mature larvae and pupae, as well as adults that were unable to emerge from the cells. These losses are attributed to low or high temperatures, or both. After emergence is complete, return the empty cocoons to the workshop and burn or bury them. This prevents females from nesting in empty cocoons and eliminates sources of infestation of bee diseases and parasites. Leaf pieces are known to carry plant diseases, and contaminated cells dumped in the field can act as sources of infestation and can promote the spread of disease.

Shelters

Construction

The size of shelters is governed by economic use of construction materials, transportability to and from seed fields and between fields, and volume of space for storage over the winter. Shelters protect the hives and the nesting bees from adverse weather. Because they are large and easily visible, the shelters help the bees return to their hives.

Beekeepers have constructed many different designs. Some allow efficient use of the pollinators and others do not. Various shelter designs have been evaluated on the basis of construction materials, heat buildup, light intensity, wind turbulence, and orientation patterns. Some of these factors influence the foraging activity of the bee, the biological factors of bee production, and the dropping of leaf pieces used to construct cells.

Shelters made of compressed particle board are unsatisfactory. They do not withstand several years of use. In comparison, shelters made of standard fir plywood and spruce studs are reusable and withstand high winds and rain. Also, these materials are inexpensive and readily available. Shelters stained with a solid color require less care than those painted with exterior latex.

Previous shelter designs called for solid construction. Those shelters were awkward to transport in utility trailers or on flatbed trailers and required two people to handle them. The two collapsible shelters described here (Fig. 13) are superior to others tested for bee productivity, are easily constructed with a minimum of materials, are highly portable, and occupy little storage space. Either wood or polystyrene nesting materials can be used in both designs.

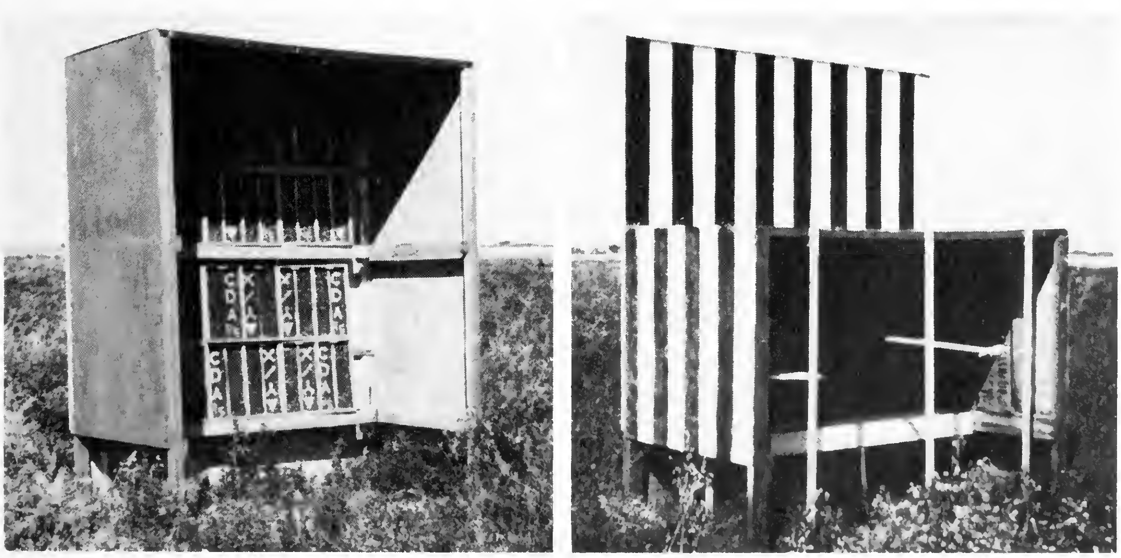


Fig. 13 Double-decked shelter (*left*) and shelter with vertical extension (*right*) that contain hives for alfalfa leafcutter bees.

Double-decked shelters

The double-decked design (Figs. 13 and 14) reduces drift of bees within or outside the seed field and increases bee populations. Its large silhouette helps the bees to find their hives and tunnels. The openness of this design results in a high light intensity throughout the day across the

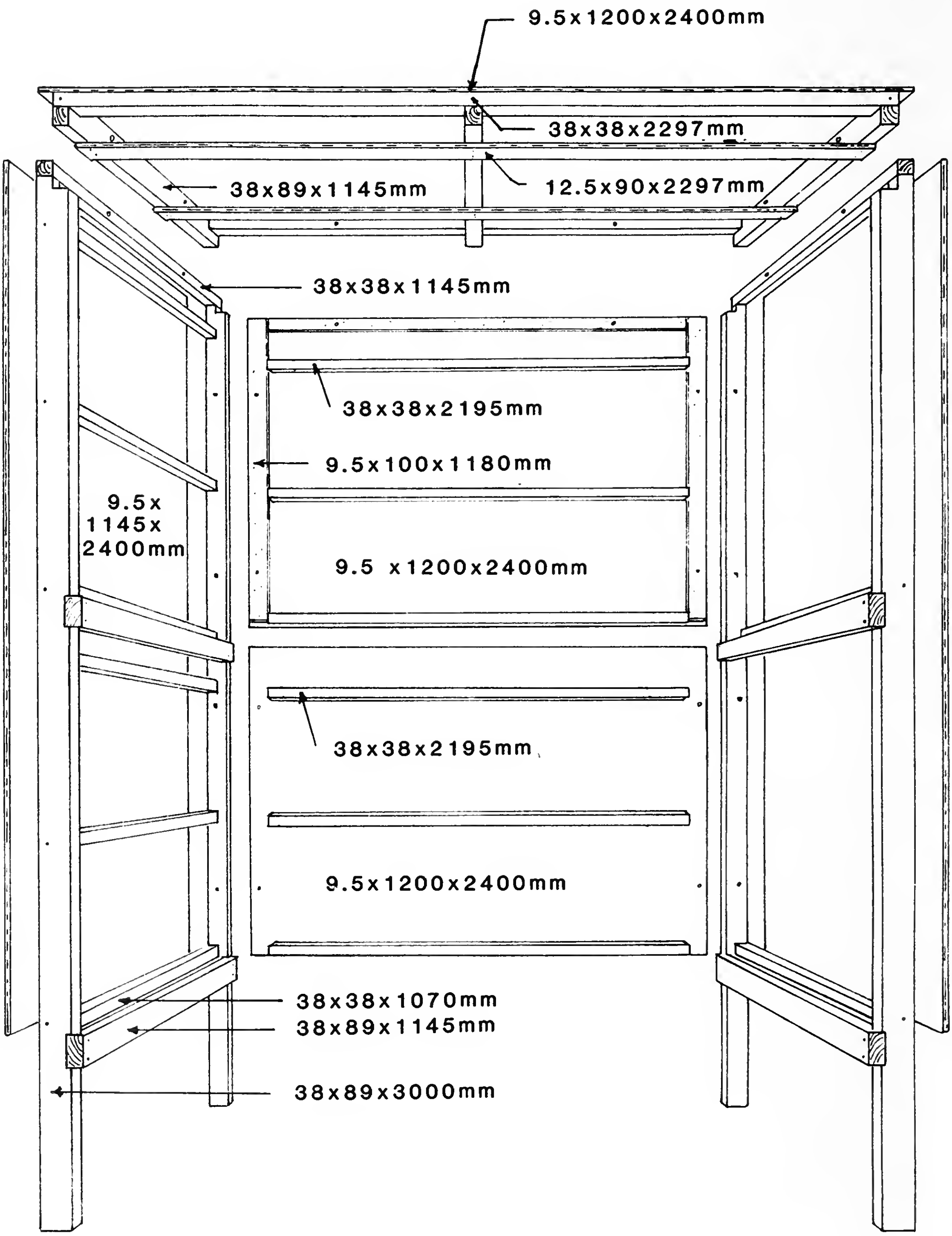


Fig. 14 Plan for a double-decked shelter.

tunnels of the hives. Direct sunlight reaches part of the bottom hives until about noon. This brightness results in increased foraging activity by the females. These shelters hold 12 hives on the back wall in two sets of six, one above the other, and an additional four hives on each side wall. When wood is used as a nesting material, females tend to use tunnels evenly across all 12 hives, with a slight preference for the upper six hives. When polystyrene is used, females prefer the upper six hives. Tunnels in the upper left-hand corner tend to be filled first. A length of baling wire strung from the inside corners of the shelter about two-thirds of the way up the hives holds the hives in place. Strips of 38 × 38 mm spruce wood across the back and sides of the shelter are positioned to keep the hives from resting against the walls of the shelter. The top and both sections of the back are bolted to the sides. The incubation trays are placed immediately beneath the top. Paint the top of the shelter black to absorb heat and radiate it to the incubating cells below. Guy wires must be used to anchor this shelter because its height increases the chances of its being blown over by high winds. Major construction materials include the following:

Quantity	Size	Material	Purpose
4	38 × 89 × 3000 mm	spruce	legs
12	38 × 89 × 2400 mm	spruce	frame for top and sides, hive spacers for sides and back, hive supports
5	9.5 × 1200 × 2400 mm	fir plywood	top, sides, back
3	19 × 89 × 2400 mm	spruce	supports for back
2	9.5 × 100 × 2400 mm	fir plywood	top section of back
2	12.5 × 90× 2400 mm	fir plywood	tray supports
14	M10 × 100 mm	bolts	

Standard shelter with extension

This shelter (Figs. 13 and 15) is the conventional size used in Western Canada. It holds six hives along the back and two on each side. Tunnels in the upper left-hand corner tend to be filled with cells first, followed by those across the top and down the two sides. Preference for these positions is probably related to temperature and light stimuli in the shelter. Because new hives are not as attractive as those in which bees have nested, do not mix new and old hives in a shelter. Put new hives in shelters that normally attract bees, usually those farthest east or south and those on the edges of fields. An excess number of tunnels will encourage bees to spread uniformly throughout the hives. It will also encourage high production with few incomplete cells and impede the development of molds in polystyrene boards.

The top of the shelter is bolted to the sides and back. When the top is removed, the sides fold against the inside of the back. The incubation trays are placed immediately beneath the top. Paint the top of the shelter

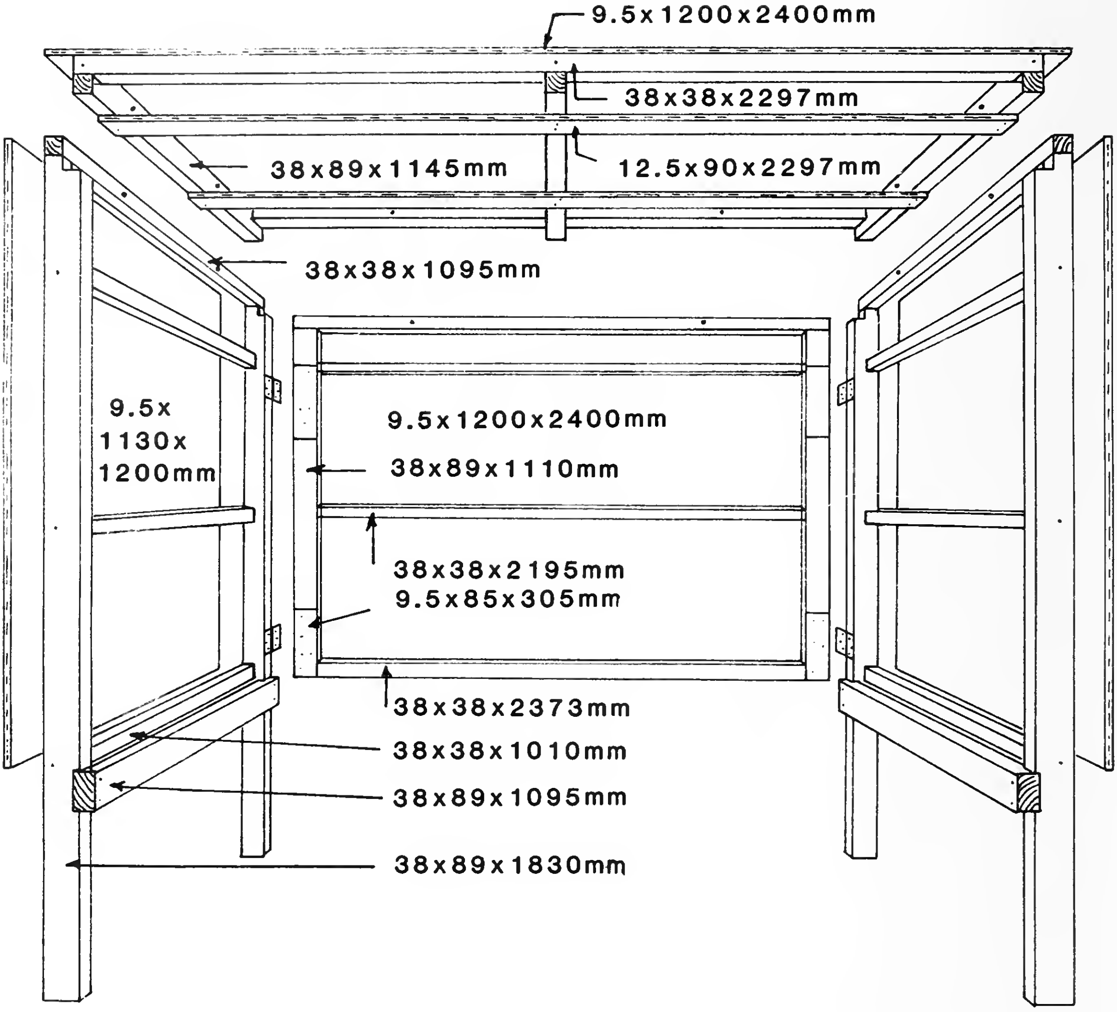


Fig. 15 Plan for a standard shelter.

black to absorb and radiate heat to the incubating cells immediately below. Anchor the extension on the shelter with guy wires because its height makes it vulnerable to high winds. Major construction materials include the following:

Quantity	Size	Materials	Purpose
9	38 × 89 × 3600 mm	spruce	legs, frames for top, sides, back; hive spacers for back and sides; hive supports for back and sides
4	9.5 × 1200 × 2400 mm	fir plywood	top, sides, back, extensions
2	12.5 × 90× 2400 mm	fir plywood	tray supports
4	#808, 80 × 80 mm	Stanley, broad butt hinges, steel-fasten pins	
6	M10 × 100 mm	bolts	

All shelters are anchored beside each leg by the use of 600-mm T bar fencing, wire, and nails to reduce the risk of being blown over. Because the shelters are collapsible, they can be handled and erected by one person. Several can be transported to and from fields at one time in utility trailers or flatbed trailers.

Temperature and light intensity inside shelters change continually throughout the day. Temperatures tend to increase during the day, maximize in late afternoon, and gradually decrease at night. Certain areas in a shelter, such as the upper left-hand corner, tend to be warmer than others. Temperatures as high as 25°C above prevailing air temperature (25–30°C) have been recorded in the backs of tunnels of hives placed flush against the wall of the shelter and behind the hives in the shelters. The trapped heat, high enough to cause larval mortality, is reduced by increasing to 150 mm the space between the shelter wall and the back of the hive. This space increases air flow and reduces moisture accumulation and growth of plant foliar molds in tunnels of polystyrene nesting material. Light intensity is similar in all types of shelters until midmorning, except in the brighter double-decked ones. After that, light gradually declines as the day progresses. Shelters deeper than 1800 mm have low light intensity at the face of the hives, which results in poor bee production. Shelters with opaque fiberglass tops are 3.5 times brighter in midafternoon than those with solid plywood tops. Females forage from them longer but produce fewer cells. Heat accumulation attributable to a fiberglass top has not been detected. Small shelters, 1.2 m square, of polyethylene sheeting or wood construction tend to be bright, but more of them are required per field area. In addition, they build up excessive heat, lack details for orientation, do not withstand winds, increase drift of bees, and hold few hives.

Position the shelters so that they face east or slightly southeast. Bees warm up and respond to the increased light intensity earlier in shelters that face an easterly direction than in those that face other directions. Direct sunlight on the face of the hives later in the day should be avoided, because prolonged high temperatures cause mortality of larvae.

Excessive air turbulence and velocity inside the shelter cause females to drop pieces of leaves as they return to the hives. If a leaf piece is dropped, the female must return to the leaf source to cut another, thus creating a loss of foraging time and productivity. In one instance an estimated 500 000 leaf pieces were dropped in 5 days from a shelter where air turbulence and velocity were considerable. Air turbulence and velocity are lowered by extending the back (skirts) to the ground and above the top (sails) (Fig. 13). The wake in front of this shelter is large, extending as much as 7 m, and the velocities are lower. Thus, flight in this zone is easier than in front of a standard shelter. High-velocity air flow under the shelter is eliminated and, although there is still turbulence within the shelter, velocities are considerably reduced.

Bees use landmarks for homing by first relating the nest entrance to large objects, such as shelters. As they approach the nest entrance, they relate to progressively smaller details. Thus, the shelter should contrast with the environment. A green shelter would not contrast with a field of

alfalfa, and uniform black lacks the detail necessary for close-range homing. Silhouettes and orientation patterns are important to render each shelter unique, since a larger number of visual clues increase the chances that the bees will find their own tunnels in the hives. Shelters with high profiles, painted with black and white vertical stripes, 150 mm wide, consistently produce more bees and reduce drift of bees within fields compared with shelters with lower profiles and no orientation patterns.

Placing the shelters in the field

Space shelters evenly through the crop, with one shelter for every 1.2 ha. Bees tend to pollinate alfalfa about twice as far to the east as to the west of the shelter; therefore, place the western shelters closer to the western edge of the crop than the eastern shelters to the eastern edge. Areas of pollination from shelters should overlap. Shelters placed on the edges of fields force bees to pollinate in only one direction. Attempts to cover several hectares with a large shelter result in an uneven setting of seed across the field. Bees often drift from shelters in the central part of a field to those on the edges. When various shelter designs (either standard, double-decked, or sails and skirts) are used throughout a field, be sure to position the latter two types in central areas of the field or wherever the bees have a tendency to drift. Remember, the direction of prevailing winds influences drift, especially early in the season. It may be necessary to place extra hives in a shelter to which bees have drifted. Bees cannot be induced to return to shelters by moving occupied hives at night from overpopulated to underpopulated shelters in the same field. They will return to the original shelter the next day.

For shelters positioned along irrigation ditches within fields, the ditch bank provides bare ground for the bees to alight and absorb heat and tends to influence the flight distribution across a field. Also, shelters located beside irrigation ditches can be serviced without driving trucks or tractors into the crop. When shelters are not on ditch banks, provide an area of bare ground immediately in front of each shelter as a place for the bees to alight, rest, and absorb heat.

Good pollination is usually obtained with about 60 000 bees per shelter (20 000 per 0.4 ha). However, the number of bees needed to pollinate a crop varies according to the weather, the amount of bloom, the time spent flying from flower to flower, and the number of days that flowers are available for pollination. The more flying time the bees have, especially during the first 3 weeks of the pollinating period, the fewer bees will be needed. The amount of bloom varies with crop characteristics, including age of stand, cultivar, and plant density, and depends on whether the crop is irrigated or dryland. For example, the number of bees required for a first-year stand of a dryland cultivar in 2-m row spacing under dryland conditions is much lower than for a fifth-year stand of a Flemish cultivar in 1-m row spacing and under irrigation.

Bees should be placed in the field when flowering begins. Females pollinate flowers immediately in front of the shelter first and then forage

at increasingly greater distances from the shelter. Thus, on subsequent days and as new florets open, pollination occurs rapidly and the bees become more evenly distributed across a field. Although not all flowers visited produce pods, most pods develop from flowers pollinated within a few days after opening. A floret may open at any time of day. It remains open for about a week if not pollinated, but wilts within a few hours after pollination. If bees are not placed on a field until full bloom, which may occur within a week after the beginning of flowering, many florets may be left unpollinated because the bees do not have time to visit them all.

Unlike the honey bee or bumble bee, which may forage for several miles, the alfalfa leafcutter bee is not a strong, long-distance flier. It ranges no farther than necessary for food gathering. This explains why seed yields are usually highest immediately in front of shelters and decrease with the distance away from the shelter (Fig. 16).

When flowers are pollinated as soon as they open, racemes have developing seed pods on the lower parts, a band on one to four open florets in the middle, and unopened buds toward the top. A field with an optimum number of leafcutter bees and well-timed pollination has a grayish appearance instead of showing profuse bloom.

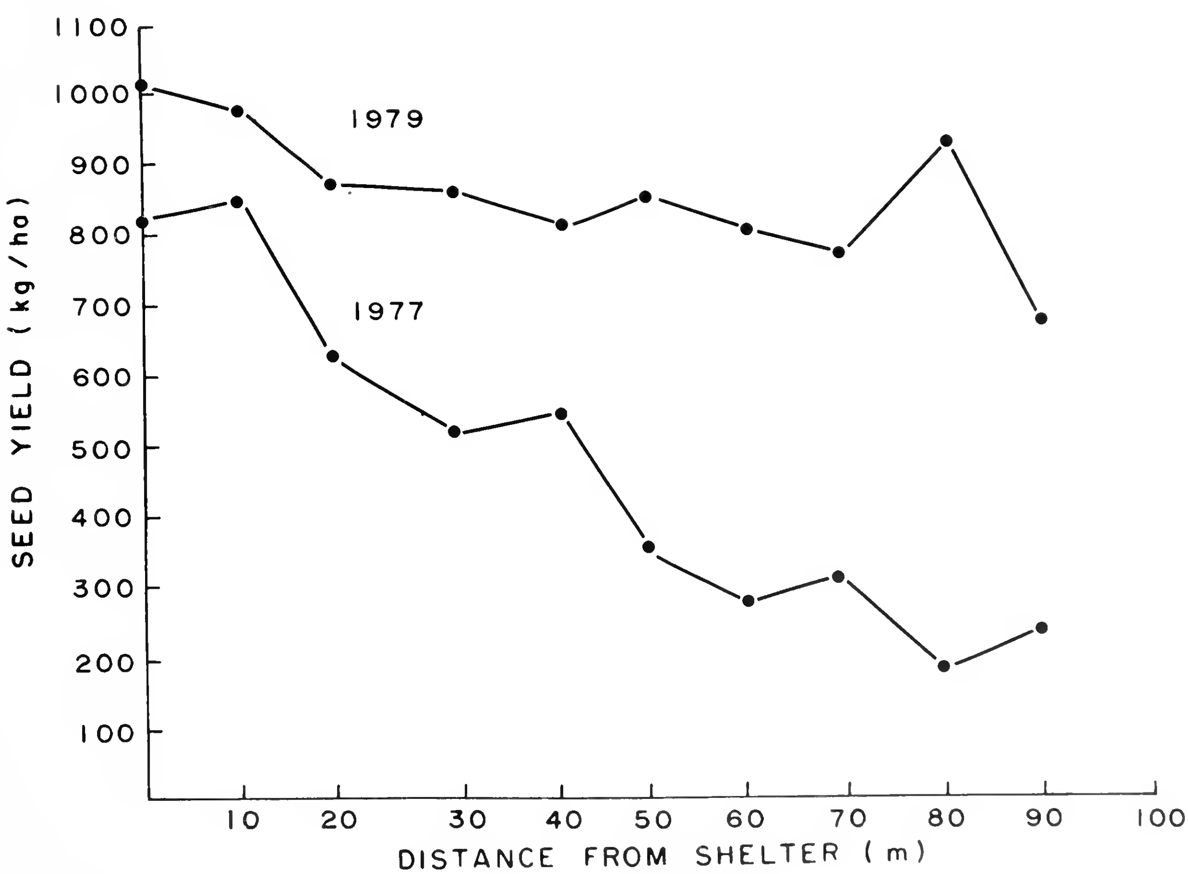


Fig. 16 Alfalfa seed yields decrease with distance away from shelter.

In Western Canada, shelters rarely need to be moved during the season. The season is too short and cool to achieve a quick uniform setting of seed or to obtain a forage harvest and a seed harvest from the same stand in the same year. Losses of leafcutter bees occur if they are relocated. If relocation is necessary, minimize losses by moving the bees with their original shelters and hives to areas with landmarks and silhouettes similar to those of the original nesting sites. Move them only a short distance (100 m) and only after the bees have been conditioned to a shelter with orientation patterns. Move the shelters at night and during periods of low wind speed (under 16 km/h) to areas with sufficient bloom to maintain the bees.

Second-generation bees

Usually, in Western Canada, only one generation of leafcutter bee is produced per year. In some exceptionally warm years, up to 25% of the bees in a hive fail to diapause and may emerge in late August to early September. At this time the chances of successfully producing offspring or of producing mature alfalfa seed are low. Second-generation bees that emerge before hives are brought in from the field produce few cells. The cells usually fail to develop completely, apparently because larvae are too cold to feed. Bees that emerge after the hives are brought in from the field soon die.

Second-generation bees are most numerous from cells completed early in the season (Fig. 17) and the numbers decline rapidly in the cells and tunnels completed later. Cells completed first are subjected to more heat units than cells produced later, which possibly explains the rapid decrease and the extent to which environmental conditions determine the second generation. However, only about one-third of the cells produced early may produce second-generation bees, even though conditions are the same for all cells that are completed at the same time. Heredity may also be a factor in the development of second-generation bees.

A high percentage of capped tunnels early in the season results from several long, hot days, which permit females to construct and provision cells. Hives with 75% of the tunnels capped within 3 weeks of placing them in the field should be taken to the shop to control second-generation bees. Hives should be stored at 20°C for 10–14 days to allow immature larvae to finish feeding and develop to the overwintering prepupal stage. Gradual cooling of the hives simulates winter storage conditions and arrests further larval or pupal development.

Losses resulting from second-generation development can also be prevented by incubating later than usual. If incubation is delayed so that the bees emerge about 1 July, bee losses that result from the emergence of a partial second generation can be avoided. However, alfalfa seed yield may be reduced owing to lack of pollination of the early bloom.

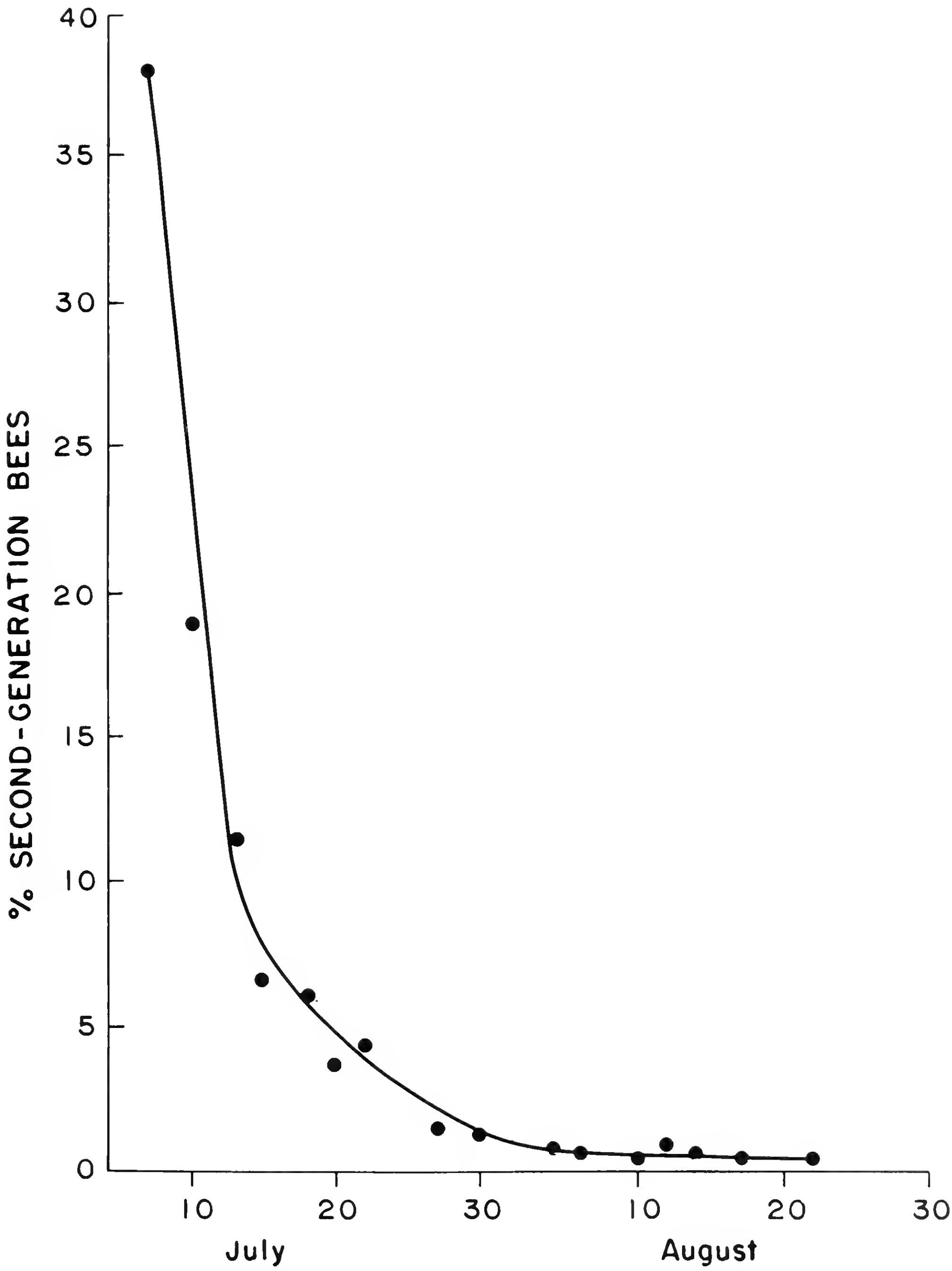


Fig. 17 Second-generation cells are produced early in the season.

Removal of hives from the field

When hives are full or when the season is over, remove and store them in an evenly heated room or building until the cells are dry enough to be removed easily from the tunnels. Hives with 75% or more capped tunnels that are removed from the field before 20 July can be replaced with additional hives. Additional bee productivity can be expected. But hives placed in the field in mid August usually produce few viable bees. End-of-season productivity is influenced by such biological factors as decreasing female populations, increased mortality of immature larvae because cool temperatures prevent feeding, movement of bee populations from full shelters to nearby and less full shelters, and amount of bloom. If a serious pest insect (e.g., grasshopper) population develops during early August, a difficult decision must be made. The choice is either to apply an insecticide (thus saving the seed crop) and terminate the bee season by removing the hives, or not to apply an insecticide (thus allowing additional bee productivity but losing some of the seed crop). The judgment is mainly economic, but seasonal history, potential seed yield, and number of females remaining for bee productivity should also be considered. Although each situation is different, it is usually advisable to remove the bees and hives and save the seed that has already been set.

No significant mortality of eggs or larvae can be attributed to jarring during transport of hives from a field. Once the hives are in storage, they should be stored at 20°C for 10–14 days to allow immature larvae to finish feeding and develop to the overwintering prepupal stage. Hives can then be cooled gradually, as if simulating winter storage conditions, which essentially arrests any further larval or pupal development. Some second-generation adults may emerge and are lost, especially if the weather remains warm. Hives removed early from the field definitely need gradual cooling or the bees will progress to adults.

If severe mold problems on the polystyrene boards are likely, remove the boards from the hives and carefully pry them apart. This allows the cells to dry and impedes further development of the mold. If parasites are also anticipated, this practice is not recommended because the cells are exposed and susceptible to infestation.

Cell remover

Although the cell remover (Fig. 18) makes it easy to remove bee cells from the grooved boards, it is rather complicated and difficult to build. A 3000-tunnel hive made with 30-tunnel polystyrene boards and containing about 20 000 cells can be stripped and the cells made ready for winter storage in less than half an hour. Several types of cell removers are available commercially.

The manual cell remover can be made in various forms and can include hand paddles made of wood or metal. One manual type is made of plywood with aluminum chutes for cells and boards and a removable head with dowel teeth. Carefully pry the grooved board apart and push each board past the dowels. Be sure that the pointed dowels remove the cells

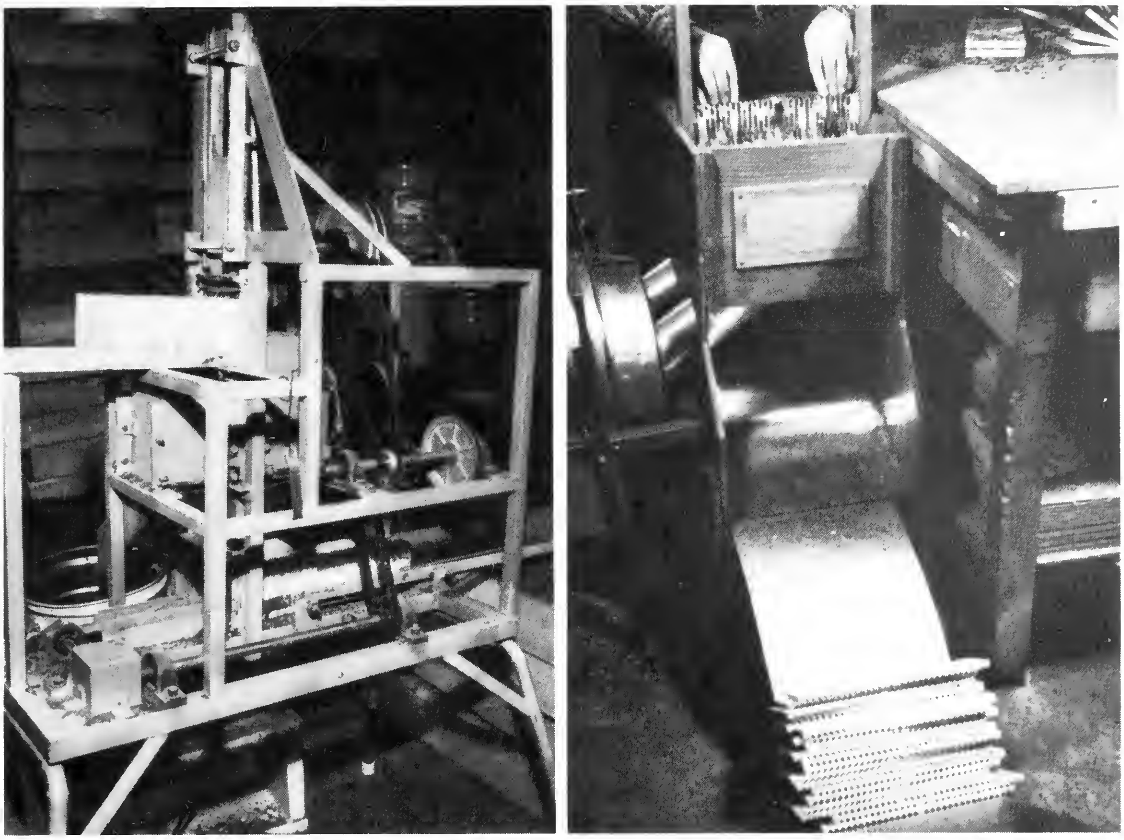


Fig. 18 Automatic (*left*) and manual (*right*) cell removers.

without piercing them. If some cells are destroyed, adjust the shims on the head of the cell remover so that each dowel slides along the bottom of the tunnel groove. The boards slide down the curved aluminum chute and stack automatically against the adjustable end wall of the chute. About one-third of the boards in a hive can be stacked before the pile becomes too high and must be removed from the stacker and replaced in the hive. To protect the wooden cell remover from wear and to make decontamination easy, paint each part with polyurethane before and after assembly. The cell remover can be steam cleaned when necessary.

The automatic cell remover can be used on both polystyrene and wood nesting materials and is preferred by most beekeepers. A plunger operating at variable speeds can force from 50 to 120 boards per minute through a metal-toothed head. The boards are fed and replaced in their original alignment. Various adjustments can be made to the machine to reduce problems with warped or sloped boards. Be sure the teeth of the head are blunt, rounded, and always clean. If the teeth are too sharp and material accumulates on the head, cocoons can be squashed or dented. Prepupae in dented cocoons usually die.

Tumbler

A motor-driven cylindrical tumbler (Fig. 19) is used for removing debris, debris-feeding insects, predators, and mold after the cells have been stripped from the grooved boards. The tumbler can deliver the

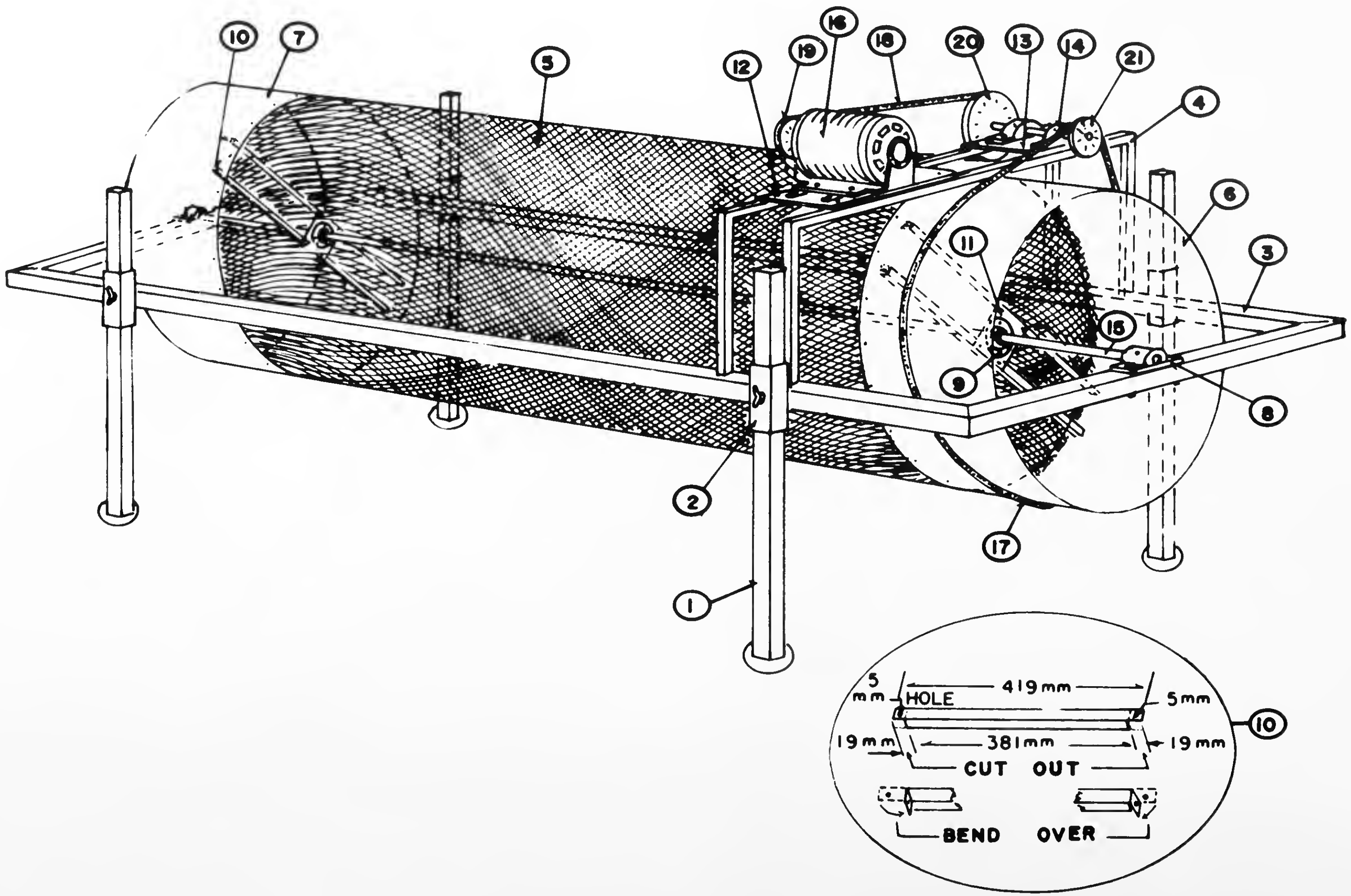


Fig. 19 Plan for an automatic tumbler.

(1) Four legs: 25.4 × 2.54 mm steel square tubing, 600 mm long; or 33.4 mm pipe.

(2) Four leg brackets: 31.8 × 2.54 mm steel square tubing, 100 mm long; or 42.2 mm pipe; with set screw for tightening.

(3) Frame: 31.8 × 2.54 mm steel square tubing, two pieces 1855 mm long and two pieces 110 mm long; or 38 mm angle iron.

(4) Frame for motor and reduction drive: 15.9 mm thin-wall steel square tubing; or 19 mm angle iron; two pieces 470 mm long and four pieces 305 mm long.

(5) Expanded metal screening: diamond-shaped opening, 4.75 mm; 0.91 mm (3/16 in., 20 gauge standard) thick; size of sheet used 1200 × 1200 mm (overlap 20 mm and rivet).

(6) Galvanized metal band: 1.22 mm (18 gauge) × 255 mm × 1200 mm (shaped to fit over screening, detail (5) and the ends welded).

(7) Galvanized metal band: 1.22 mm (18 gauge) × 305 mm × 1200 mm (shaped to fit over screening, detail (5) and ends welded).

(8) Two solid mounting brackets: made from a pipe 16 mm in diameter and 32 mm long, welded to a 6 × 32 × 65 mm plate.

(9) Two bearings: self-lubricating pressed-steel self-aligning flange units, 15.9 mm bore.

(10) Four spokes: made from 16 mm angle iron, 420 mm long; see detail (1) for construction.

(11) Two plates: 1.22 mm (18 gauge) galvanized metal 100 mm × 100 mm with center cut out to fit bearings.

(12) Plate for motor mount: 1.22 mm (18 gauge) galvanized metal 150 × 200 mm with slotted holes.

(13) Plate for reduction drive mount: 1.22 mm (18 gauge) × 127 mm × 150 mm galvanized metal.

(14) Reduction drive unit: 12.7 mm shaft, 255 mm long.

(15) 15.9 × 1880 mm solid steel shaft.

(16) Motor: 186 watt.

(17) Sewing machine belt.

(18) Standard V-belt to size.

(19) Pulley, 64 mm.

(20) Pulley, 203 mm.

(21) Pulley, 57 mm.

cleaned cells directly to the incubation trays or storage containers. The motor should be large enough to rotate the drum and propel the cells about halfway up the side of the drum. To avoid inadequate removal of debris and debris-feeding insects, the cells should not centrifuge or pass through too quickly. Figure 19 shows parts for the motor-driven tumbler.

Plans for a hand-cranked tumbler may be obtained from the Research Station, Lethbridge. The hand-cranked tumbler provides better quality-control than the motor-driven tumbler, but is slower. A fanning mill is sometimes used, especially for removing second-generation cells, but it does not remove most debris as efficiently as a motor-driven tumbler.

Tumble the moldy cells outdoors or under an exhaust fan, because the mold spores, which come off in clouds, may cause allergies in humans. Wear a surgical mask when stripping moldy cells, especially those from polystyrene nesting material, or when mold spores from the tumbler are not being carried away by the wind or a fan. Tumble the cells until most of the mold spores are dispersed and until leaf pieces or other debris stop dropping through the screen. Do not overtumble and expose prepupae. Some leaf pieces on the cells are necessary to ensure emergence.

Estimating production

Many factors influence yearly cocoon production including geographic location, bee management practices, agronomic practices, environmental conditions and developmental rate during the summer, and occurrence of parasites or predators. To improve beekeeping practices and to determine the number of viable bees and parasitized cells, and the sex ratio, samples need to be taken and estimates made.

Beekeepers who anticipate either domestic or export sales of bees can submit samples to the Canadian Leafcutter Bee Cocoon Testing Centre at Brooks, Alta. The Centre provides unbiased and accurate estimates of samples to help sellers obtain fair prices and buyers fair value. Beekeepers who have few bees or who do not require the accuracy of the Testing Centre can use the methods that follow. An initial sample of 200–300 g is taken to be as representative as possible of the bulk population. Cells produced from various shelters and alfalfa fields should be tumbled and mixed thoroughly before the sample is drawn. If the sampling is not random, the estimates will be inaccurate. From this initial sample, 10 15-g subsamples can be drawn. The number of subsamples and the size or weight of each subsample depend upon the accuracy needed for the estimates. The more subsamples you take, the more accurate your estimate will be. The intact cocoons can be separated from other cells by pressing and rolling the head end of the cell between thumb and forefinger. A cell that does not contain an intact cocoon usually collapses. Record the number of intact cocoons, incomplete cells, and second-generation cells in each subsample. Calculate the average number of cocoons per 15 g from the 10 subsamples. Multiply the average number

by 1000 and divide by 15 to determine the number of cocoons per kilogram. All intact cocoons can then be incubated to determine the number of females, males, dead pupae or prepupae, and parasites present in each subsample. Live prepupae and parasites can also be determined by cutting intact cocoons at the head end with a sharp knife. The sex ratio cannot be determined without an incubation test. Check the samples daily, and record and remove the parasites and the cells from which they emerged. If the parasites are not removed, they will mate, anesthetize and lay eggs on the occupants in the other cells, and stop development of the bee larvae or pupae, thus creating inaccurate results. Once the number of live bees has been determined for each subsample, calculate the production per kilogram for the whole population.

Estimates of production can be done at any time of year; however, incubation takes less time in spring than in the fall. Yearly records will indicate if parasites are being controlled and other management practices are improving.

In samples submitted by beekeepers from across Western Canada over the past 10 years, the average number of cocoons per kilogram was about 8000 (range: 4300 to 10 700/kg), and 20–30% of the cells did not contain intact cocoons. The cocoons that were incubated contained the following: 33% females, 60% males, 0.5% chalcidoid wasps, and 6.5% dead prepupae.

Bee protection

Most insecticides recommended to control pest insects of forage crops are harmful to the alfalfa leafcutter bee. In general, insecticides applied to crops during bloom are the most poisonous to bees. Bee poisoning can also occur when toxic sprays or dusts drift to adjacent crops that are in bloom. Bees may be poisoned by contact with insecticide residues on plants, by collecting or touching contaminated water on foliage or flowers, and by collecting contaminated pollen or nectar. Various procedures can be followed to reduce the chance of pesticide–pollinator interactions. Survey the fields frequently for pest insects before the crop blooms. If insecticides are needed they can be applied most effectively at critical stages in the development of the pest insects. Harsh insecticides can be used in the prebloom application before the bees are in the field. If interference with the bees is anticipated, bee incubation can be prolonged by lowering the temperature in incubators until any remaining residues of the insecticide dissipate from the field. Other measures include applying sprays only in the evening or at night when bees are out of the field, covering hive or shelter fronts to reduce drift of sprays into hive tunnels, or removing bees to another field.

Theft of hives from the field and of cells from storage over the winter has occurred. Theft can be reduced by providing identification marks (e.g., symbols, initials) painted on the front of the hives, by branding initials on the sides, or by applying pressurized impressions of symbols or

initials on the sides or back of hives. Also, fluorescent dusts, dyes, or sprays can be put inside hives, on nesting materials, or mixed with cells once they are removed from hives. Grain confetti used as markers and sprinkled into tunnels may be incorporated with leaf pieces into cells. A notice placed in the shelters that hive equipment and bees are marked for protection deters theft. Check hives often and bring them in when filled to prevent extended exposure to thieves. Cooperate with your neighbors by reporting unauthorized vehicles in their fields or near beekeeping equipment.

Parasites and predators

The loose-cell system of bee management enables control of natural parasites or predators that prey on the bee or feed on stored products. The system has been criticized because the types of hives and laminated grooved nesting materials and the incubation of loose cells in trays are conducive to population increase of harmful insects. However, these criticisms are unfounded. Over the last 10 years, mortality attributable to parasites or predators accounted for less than 1% of the total bee population across Western Canada. Under the intensive loose-cell system of bee management, parasites or predators can be controlled by precise construction of hives, controlled incubation and light traps, and physical separation during the removal and subsequent tumbling of cells from the hives. The chalcid wasps (Fig. 20), especially *Pteromalus venustus*, are the most common of the 21 species of insects associated with the bee. These pest insects are often associated with other native bees and wasps, and beekeepers with higher than average numbers of native bees in their operation tend to acquire various types of pest insects first.

Pteromalus venustus Walker

Pteromalus venustus is the most common chalcidoid wasp parasite associated with the alfalfa leafcutter bee in Western Canada. This wasp was accidentally introduced from Europe and probably arrived in Canada with the bee. It occurs in some proportion in all beekeeping operations.

Adult females are 2.5 mm long and males are 2 mm long. Females are black with dark brown on the legs, and males are similar but have a metallic green head. Females have a slender ovipositor (egg-laying organ) and enlarged hind legs. Adults emerge through a single hole chewed through the leafcutter bee cell. Males usually emerge before females.

Females of *P. venustus* pierce the cocoons of their hosts with their ovipositors to anesthetize the hosts and lay eggs. In one 4-hour period, 110 eggs were laid on the surface of a bee larva by a female; usually, fewer eggs are laid. Eggs hatch in 1–2 days, depending upon temperature, and

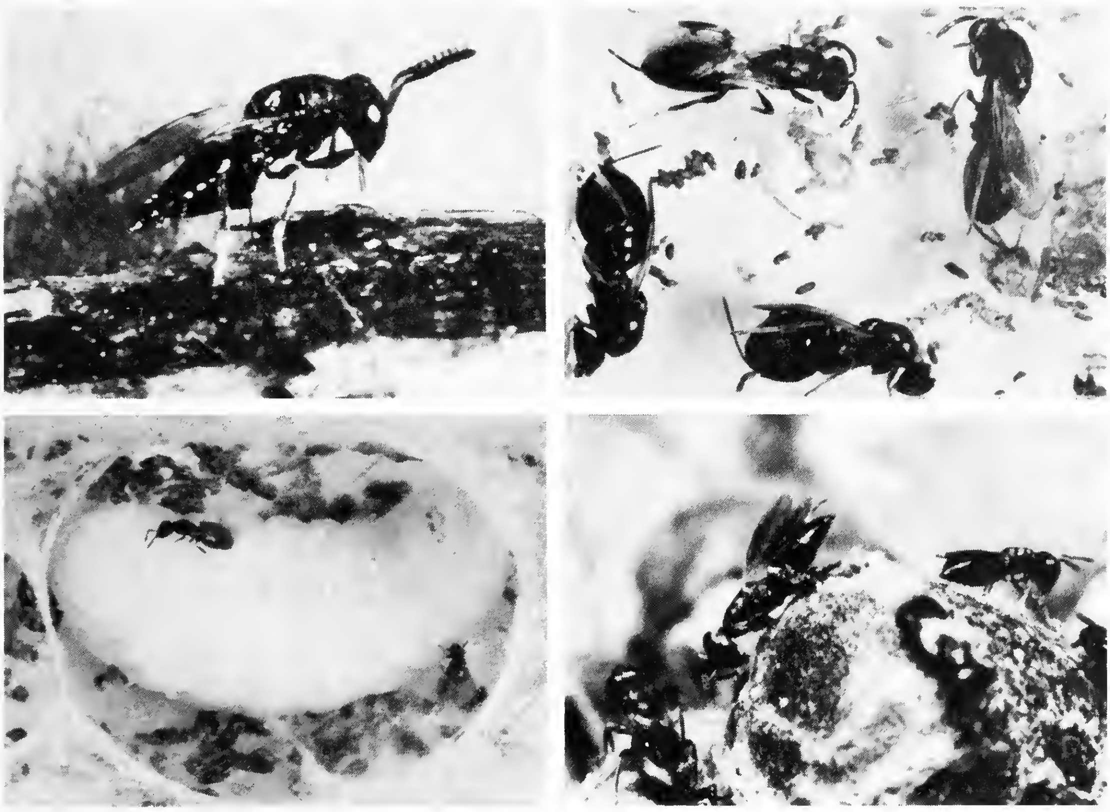


Fig. 20 Adult chalcid wasps: *Pteromalus venustus* (top left), *Monodontomerus obscurus* (top right), *Melittobia chalybii* (bottom left), and *Dibrachys confusus* (bottom right).

the small white hairless larvae attach themselves to the paralyzed bee and begin feeding. The parasite larvae are about 2.5 mm long when mature (Fig. 21). There is considerable mortality of eggs and larvae, partly because of cannibalism, but not of pupae. Larvae can either progress directly to the adult stage or remain as mature larvae and enter the overwintering state. Overwintering larvae require some cold treatment before progressing to the adult stage. Adults and larvae sometimes occur in the same cell. Adult parasites emerge over a 4-day period starting on the 8th or 9th day of incubation. The wasp develops so rapidly at 30°C that if it is poorly controlled during first emergence, another emergence can occur before or just as the bees are taken to the field, thus resulting in another loss of unemerged bees owing to the parasites. The number of parasites completing development per cell depends on the number of females laying eggs in that cell. When only one female lays eggs in a cell, about 16 adults (range: 7–26) are produced, but the number of adults produced per cell increases when several females lay in a cell, even though the number of adults produced per female decreases. The male-to-female ratio averages 1:3. Unmated females produce only male offspring.

Fig. 21 Comparison of mature larvae of *Melittobia chalybii* (left), *Pteromalus venustus* (center), and *Monodontomerus obscurus* (right).

Monodontomerus obscurus Westwood

Monodontomerus obscurus is widespread in nests of wild bees across North America, especially where the alfalfa leafcutter bee is used. In Canada, it was more common when bees were imported from the United States than it is now.

Adults are shiny, metallic blue green with red eyes. Females are 3.5 mm long and males are 2.5 mm long. Females have a long slender ovipositor and enlarged hind legs. Males emerge before females through a single hole from the cocoons in which they developed.

The female anesthetizes the bee larvae with her ovipositor, and then in the space between the host and the inner wall of the cocoon lays 3–51 (average: 10) slender eggs. Larvae of *M. obscurus*, unlike those of *P. venustus* and *Melittobia chalybii* (Fig. 21), are sparsely covered with bristly hairs. These hairs aid the first-instar larvae to reach the host. The average time from egg to adult is about 20 days at 30°C. The average male-to-female ratio is 1:3. The average number of parasites that complete development per bee cell is 10 (range: 3–27). Unmated females produce only male offspring. Parasites overwinter as mature larvae, and adults emerge over a 7-day period beginning about the 10th day of incubation. Even if the chalcid is poorly controlled during its emergence, a second emergence in the incubator is unlikely. However, in some cases, when

incubation trays are left too long in the field and contents are not discarded, another emergence may occur. Leafcutter bees are susceptible to attack up to one day before emergence.

Melittobia chalybii Ashmead

Melittobia chalybii is widespread in North America, mainly parasitizing nesting solitary and social wasps and native bees, including leafcutter and bumble bees. Although *M. chalybii* is rarely encountered in alfalfa leafcutter bee operations, its array of alternative hosts suggests that it is found in all areas of Western Canada where alfalfa seed is produced. Its small size, high reproductive rate, and potential for several generations per year suggest that if it is encountered in a beekeeping operation, this species could be a serious pest.

Adults are small, about 2 mm long, and black to dark brown. Males lack wings, whereas females are normal. Courtship and mating take place within a cocoon. Males live in the cocoons in which they developed and apparently can neither see well nor fly. Although males can use exit holes made by females, dead males are found in cocoons from which females have emerged. Unmated females sometimes lay a few eggs that become the males with which they mate to produce numerous offspring.

Within a day after mating, females chew holes in cocoons and enter them to anesthetize, feed on the fluid from the wound, and lay eggs on the surface of the bee. The larvae are about 1.5 mm long when mature. Several generations per year are possible, because egg to adult takes 17 days at 20°C and larvae do not require a cold overwintering treatment for development. A leafcutter bee larva supports about 175 (range: 74–281) parasite larvae. The male-to-female ratio is 1:27. Fortunately, this parasite does not survive well during prolonged cold-storage conditions.

Dibrachys confusus (Girault)

Dibrachys confusus is widespread in Canada in a variety of native bee nests. Although this wasp has been known to be associated with the alfalfa leafcutter bee since 1967, it was rarely encountered. However, in recent years its frequency of occurrence has increased, especially in the aspen parkland areas where numerous native bees, particularly *Megachile relativa* Cresson, are nesting in hives.

Adult females are 2.5 mm long and males are 2.0 mm long. Both sexes are similar in size and shape to *Pteromalus venustus*, except that the legs of *D. confusus* are reddish yellow and the females have partly cloudy forewings. Little is known about the biology of this wasp. Adults emerge through a single hole chewed through the leafcutter bee cell. Males usually emerge before females, and a courtship pattern occurs before mating.

Females anesthetize their host before laying eggs. Eggs hatch after one day and the time from egg to adult at 30°C is 15 days. On a natural

host, *M. relativa*, the female produces 24 adults (range: 4–47) per cell. Survival of eggs and young larvae on the introduced host, the alfalfa leafcutter bee, is low and only 12 adults (range 4–41) are produced per cell. The high mortality may be a result of a necrosis of the bee once the young larvae start feeding. Because of its low survival, this parasite may not develop in importance. The male-to-female ratio averages 2:1.

Coelioxys, cuckoo bees

Three species of *Coelioxys* (*sodalis* Cresson, *funeraria* Smith, and *moesta* Cresson) have so far been recorded as parasitic to the alfalfa leafcutter bee in Western Canada. Several other *Coelioxys* species that occur in Western Canada have also been recorded as parasites in the United States. Although they are relatively rare, individuals are more common in beekeeping operations in the parkland areas of Alberta, Saskatchewan, and Manitoba than on the prairies.

Coelioxys belongs to the leafcutting family Megachilidae and, having evolved from *Megachile*, it is very similar in appearance to the pollen-collecting leafcutter bees. Cuckoo bee females lack pollen-collecting hairs on the underside of the abdomen and have a longer, more sharply pointed abdomen than the alfalfa leafcutter bee. The characteristic pointed abdomen is an obvious modification for inserting eggs into host cells. Males are smaller than females and have a broader abdomen with short distinct spines protruding from the last abdominal segment. Females can be recognized by their rapid flight in front of leafcutter bee hives as they attempt to enter tunnels to lay eggs.

Cuckoo bee females oviposit by piercing the pollen mass and leaf lining on the base or lower side of the cell and depositing the egg through a slit while the female leafcutter bee is out foraging. Only the extreme anterior end of the egg touches the pollen mass. After provisioning is completed, the *Coelioxys* egg is usually buried more than halfway below the surface of the pollen mass. The egg is colorless and has a swollen anterior end. Upon hatching, the first-instar larva is small and delicate and remains in that stage for about 11 hours. It usually feeds on pollen. The second instar is elongate and cylindrical with a large head and large, hard, sharply pointed mandibles. The larva has a pair of hornlike dorsal spines that it uses to burrow to the surface of the provisions. The third instar looks the same as the second and usually kills the host or other cuckoo bee larvae (several eggs are often laid in the same cell). Fourth and fifth instars do not have large head capsules or long mandibles and appear similar to the leafcutter bee larvae. These instars feed on the pollen without competition from host or other cellmates. After development is completed, the mature larva spins a cocoon. In an incubator, adult males and females usually emerge a few days before leafcutter bees.

Vitula edmandsae serratilineella Ragonot, driedfruit moth

The driedfruit moth (Fig. 22) is a native species found throughout North America as a pest of dried fruits such as apples and peaches, honeycombs, and bumble bee nests. It has recently increased in occurrence in Western Canada, particularly in Alberta. Infestations have been confined primarily to storage areas for hives, incubators, or workshops. The moth is most commonly seen as a mature larva when cells are removed from hives.

Adult moths are light gray with darker irregular gray markings on the wings. The wing span is 20 mm and the body is about 15 mm long. Females live about 17 days and males die in 10 days or less. Both males and females release pheromones during courtship. Females begin laying from 100 to 325 eggs in cracks of bee hives on the 3rd day after mating. The

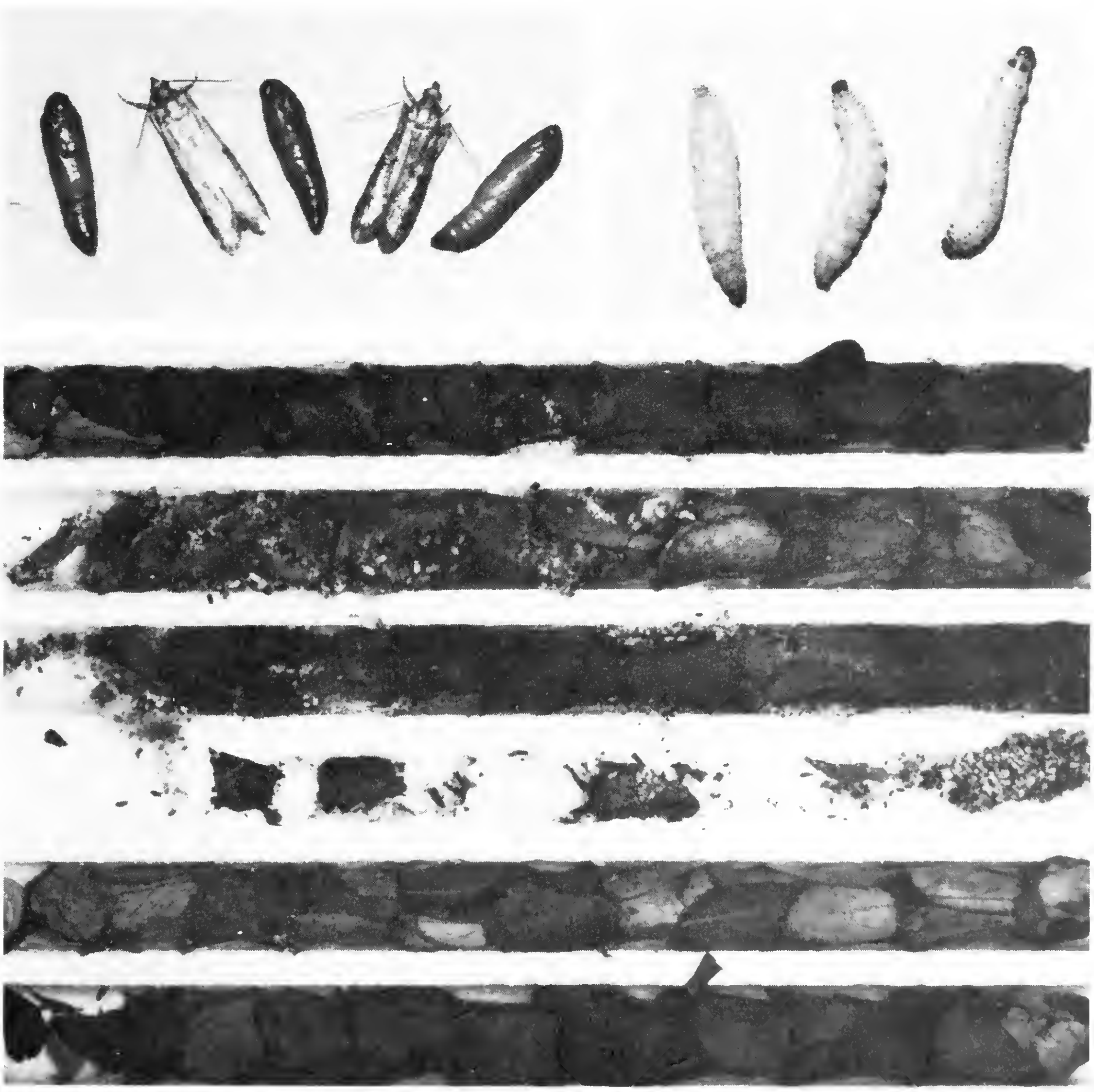


Fig. 22 *Vitula edmandsae serratilineella* adults and pupae (*top left*), larvae (*top right*), and damage by larvae to cells and polystyrene boards (*bottom*).

cream-colored eggs hatch in 4–6 days, and young larvae begin feeding immediately. Larvae invade hives through uncapped tunnels and along the sides and back of a hive. Tunnels with no bee cells are frequently used to gain access to the back of a hive. Immature larvae frequently chew across the tunnel walls of polystyrene nesting material (Fig. 22), but not the walls of wood nesting material. Polystyrene hives with numerous holes chewed through the tunnel walls are, in subsequent years, susceptible to chalcid wasp invasions.

It takes about 30 days for larvae to grow through five or six instars. The larvae feed on a variety of materials and survive better on pollen, incomplete cells, honey, and live bee larvae than on leaf pieces and dead bees. Each larva consumes the pollen and nectar provisions of about one cell in its lifetime. It may destroy up to six cocoons in a tunnel while searching for food. The larva constructs a webbed tunnel using its own frass in the construction, from which it protrudes while feeding. If disturbed, the larva will immediately withdraw into its shelter or move in an irregular manner to a sheltered area. A mature larva (Fig. 22) is about 15 mm long, white to light pink, and has a dark brown head. Mature larvae tend to leave the tunnels and food source before overwintering and aggregate in sheltered webbing clusters of up to several hundred. These clusters are often located in the space between hives. Mature larvae, not removed during tumbling of cells, web masses of cells together during winter storage and in incubation trays. Pupation lasts about 11 days and usually occurs in early spring but may occur in the fall if shop temperatures are warm. Eggs or young larvae can be taken to the field with the hives. When environmental conditions are favorable for reproduction, several generations are possible per year.

Nemognatha lutea Le Conte, brown blister beetle

The brown blister beetle is a native species that commonly occurs with large native bees in southwestern Saskatchewan and southeastern Alberta. It is more prevalent in areas adjacent to native prairie than in cultivated areas. It consumes from one to three cells, depending upon size of host, to complete development.

Adults have a yellowish tan, hardened fore wing and vary in size from 7 to 15 mm long, depending upon the amount of food the larva ate. They are commonly seen on flower heads of thistle, sunflower, or yarrow. About 200 yellow eggs are laid in masses at the base of buds and flowers of host plants. Eggs hatch into dark brown first-instar larvae (triungulin), 1 mm long, which have three claws on each leg. The beetle actively seeks the bees and uses its claws to attach itself to any bee that visits the flower. After the bee returns to its nest, the triungulin detaches itself and begins feeding on the pollen–honey provisions and the bee egg. Subsequent instar larvae are creamy white with a light brown head and are about 20 mm long when mature. Development is rapid when suitable provisions are available. When pollen in one cell is consumed, invasion into one or

Fig. 23 Pupa of *Nemognatha lutea* in cells.

two other cells occurs. The overwintering instar that is most commonly seen is the coarctate, a hard, dark brown, cocoonlike mature larva (Fig. 23). Few coarctate larvae survive tumbling because desiccation apparently occurs when the thin membranous covering is broken. Adults emerge in an incubator just before bees emerge.

Stored-product beetles

Stored-product beetles associated with the leafcutter bee include the sawtoothed grain beetle, *Oryzaephilus surinamensis* (Linnaeus); red flour beetle, *Tribolium castaneum* (Herbst); rusty grain beetle, *Cryptolestes ferrugineus* (Stephens); black flour beetle, *Tribolium audax* Halstead; smooth carpet beetle, *Trogoderma glabrum* (Herbst); confused flour beetle, *Tribolium confusum* Jacquelin du Val; and spider beetle, *Ptinus* sp. These beetles are cosmopolitan in distribution and have been found consistently in leafcutter hives, incubators, and work areas. None are important as serious nest destroyers of the bee. The adults and larvae are primarily attracted to pollen, but sometimes penetrate spun cocoons and kill bee larvae when searching for pollen. Most of these beetles are capable of feeding at low temperatures, have a high reproductive rate, and produce more than one generation a year. These beetles are often found when sanitation practices are lax or when hives are stored near infested buildings, such as old or unused granaries.

Other parasites and predators

A considerable number of other insects have been associated with the leafcutter bee across Western Canada. However, these insects have rarely been encountered and none have become significant pests under field conditions, incubation, or storage. Of this group, the checkered flower beetle, *Trichodes ornatus* Say, is considered to be potentially the most serious predator of the leafcutter bee. It is found in British Columbia, along the foothills, and northern Alberta, but not on the prairies. In the Pacific Northwest of the United States, it has consistently caused severe damage. One larva often consumes eight cocoons and destroys more than 20. Two wasp parasites, *Sapyga pumila* Cresson and *Leucospis affinis* Say, have been recorded only in the Okanagan Valley of British Columbia. This distribution is probably an extension from Washington, where both have been serious pests. Wasp larvae usually consume bee larvae and provisions. Two flies, the dewy bee fly, *Anthrax irroratus* Say, and a conopid, *Physocephala texana* (Williston), are found mainly on the prairies. The bee fly feeds on bee larvae in the tunnels. Two horny spines that project from the head of the pupa are characteristic and are used to break through the bee cell before the adult emerges. The adult conopid female captures female bees while they forage and deposits an egg on them. The egg hatches and the larva crawls inside the female bee and consumes the internal organs. The dead female can be recognized by her elongated abdomen, which contains the fly pupa. This fly is probably one of the main insects that reduce adult foraging populations. Other insects sporadically encountered include ants, dragonflies, yellowjackets, earwigs, and pollen-eating mites.

Control

Various control procedures can be implemented in the loose-cell system of management. Procedures to reduce the number of parasites that enter the hives are discussed in the section on hives. During the incubation process, the use of black (ultraviolet) lights to attract parasites to a water trap is essential. Ultraviolet lights are more attractive to the parasites than incandescent lights. Use an ultraviolet light such as the Canadian General Electric F20T12/BLB lamp in a CS6024 fixture, or its equivalent. Rated life expectancy for these lamps is about 7500 hours, but is reduced considerably with repeated starts. If the lamps appear dim or are not attracting parasites, replace them. The ultraviolet light and water bath are usually placed on the floor between the shelves. It is easier for the parasites to hop down to lights than to fly up to them. In large controlled-temperature rooms, several sets of ultraviolet lights and water baths are needed. Detergent in the water reduces surface tension so that parasites drown readily. An ultraviolet light with water bath should operate in the workshop from May to November. This will attract and control insects that escape in the shop and eliminate those that emerge from hives or are transported on hives returned from the field.

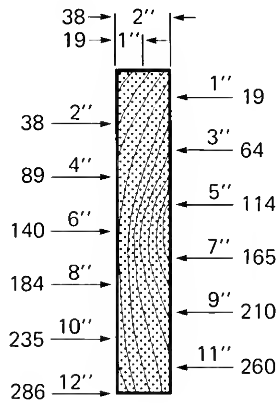
Repeated vacuuming with a household vacuum cleaner effectively removes chalcid wasps from the walls and floor of the incubator, from the fronts of the incubation trays, and from the shelf units in the incubator. Wasps can sometimes be pulled through the screen of the incubation tray by a strong vacuum. To be most effective, vacuuming should be done a few times each day when the parasites are emerging.

The use of insecticide vapor strips in incubators is effective in controlling chalcid wasps. Use the vapor strip just as the first parasites emerge and leave it in the room for about 4 days or until the parasites finish emerging. Parasites should start to die soon after they are exposed to the strip. Attaining vapor concentrations that are high enough to control parasites may be difficult in incubators with air flow in and out of the room. Additional pieces of vapor strip may be needed in incubators with a high air flow; the rate for each incubator may vary. These strips should be used with great care because high rates of exposure for prolonged periods of time may cause bee mortality. Also, vapors from most insecticide strips adhere readily to organic surfaces (e.g., wooden incubation trays) and, as the vapors are released, subsequent losses of bees may occur. After the strip is removed, open the door to the incubation room and circulate the air with fans for at least 24 hours before resuming incubation. Expose the bees to vapor strips only once.

Sprays, baits, fly strips, paints, oil baths, or grease are marginally effective in controlling chalcidoid wasps and other pest insects in an incubator. Perlite, vermiculite, or sawdust to cover the cells in incubation trays are also marginally effective in controlling parasites and reducing the parasitism of cocoons in trays. These materials, especially perlite, need to be removed from the trays and the cells again tumbled thoroughly. This additional step must be taken before the bees emerge, as these materials impede bee emergence and perlite adheres to the pollen-collecting hairs of females.

SAWN LUMBER SIZES

(soft conversion)



CONSTRUCTION PLYWOOD

modular size of a sheet 1200 x 2400 mm

imperial (nom.)	metric (actual)	
	sanded	sheathing
1/4"	6 mm	–
5/16"	–	7.5 mm
3/8"	8	9.5
1/2"	11	12.5
5/8"	14	15.5
3/4"	17	18.5

CONVERSION FACTORS

Metric units	Approximate conversion factors	Results in:
LINEAR		
millimetre (mm)	x 0.04	inch
centimetre (cm)	x 0.39	inch
metre (m)	x 3.28	feet
kilometre (km)	x 0.62	mile
AREA		
square centimetre (cm^2)	x 0.15	square inch
square metre (m^2)	x 1.2	square yard
square kilometre (km^2)	x 0.39	square mile
hectare (ha)	x 2.5	acres
VOLUME		
cubic centimetre (cm^3)	x 0.06	cubic inch
cubic metre (m^3)	x 35.31	cubic feet
	x 1.31	cubic yard
CAPACITY		
litre (L)	x 0.035	cubic feet
hectolitre (hL)	x 22	gallons
	x 2.5	bushels
WEIGHT		
gram (g)	x 0.04	oz avdp
kilogram (kg)	x 2.2	lb avdp
tonne (t)	x 1.1	short ton
AGRICULTURAL		
litres per hectare (L/ha)	x 0.089	gallons per acre
	x 0.357	quarts per acre
	x 0.71	pints per acre
millilitres per hectare (mL/ha)	x 0.014	fl. oz per acre
tonnes per hectare (t/ha)	x 0.45	tons per acre
kilograms per hectare (kg/ha)	x 0.89	lb per acre
grams per hectare (g/ha)	x 0.014	oz avdp per acre
plants per hectare (plants/ha)	x 0.405	plants per acre